Exploring the Sun with New Instruments flown on Sounding Rockets

Dr. Amy Winebarger

NASA Marshall Space Flight Center

Outline

- A little about me...
- What is the NASA Sounding Rocket program? What is it like to launch a rocket?
- An example of a very successful Sounding Rocket
- Summer Research at MSFC

Career Path


1991

King College

91-95

UAH
The University of Alabama in Huntsville

95-99

CfA

99-01

Naval Research Laboratory
Washington, DC

02-05

06-10

NASA

10-??

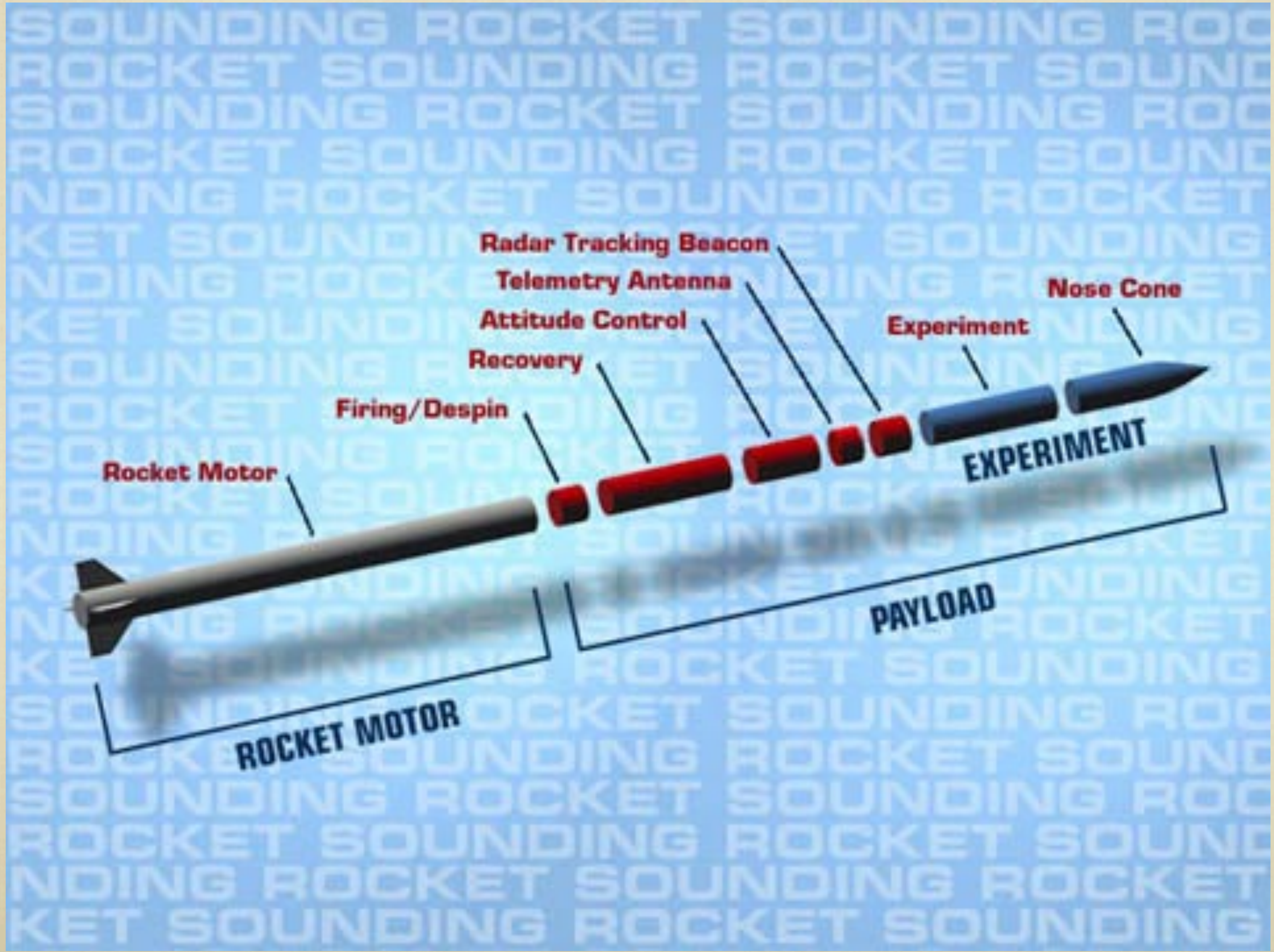
Sounding Rocket Program

- To sound – Throw a weight into the water to measure its depth
- Sounding Rockets – Rockets that make scientific measurements

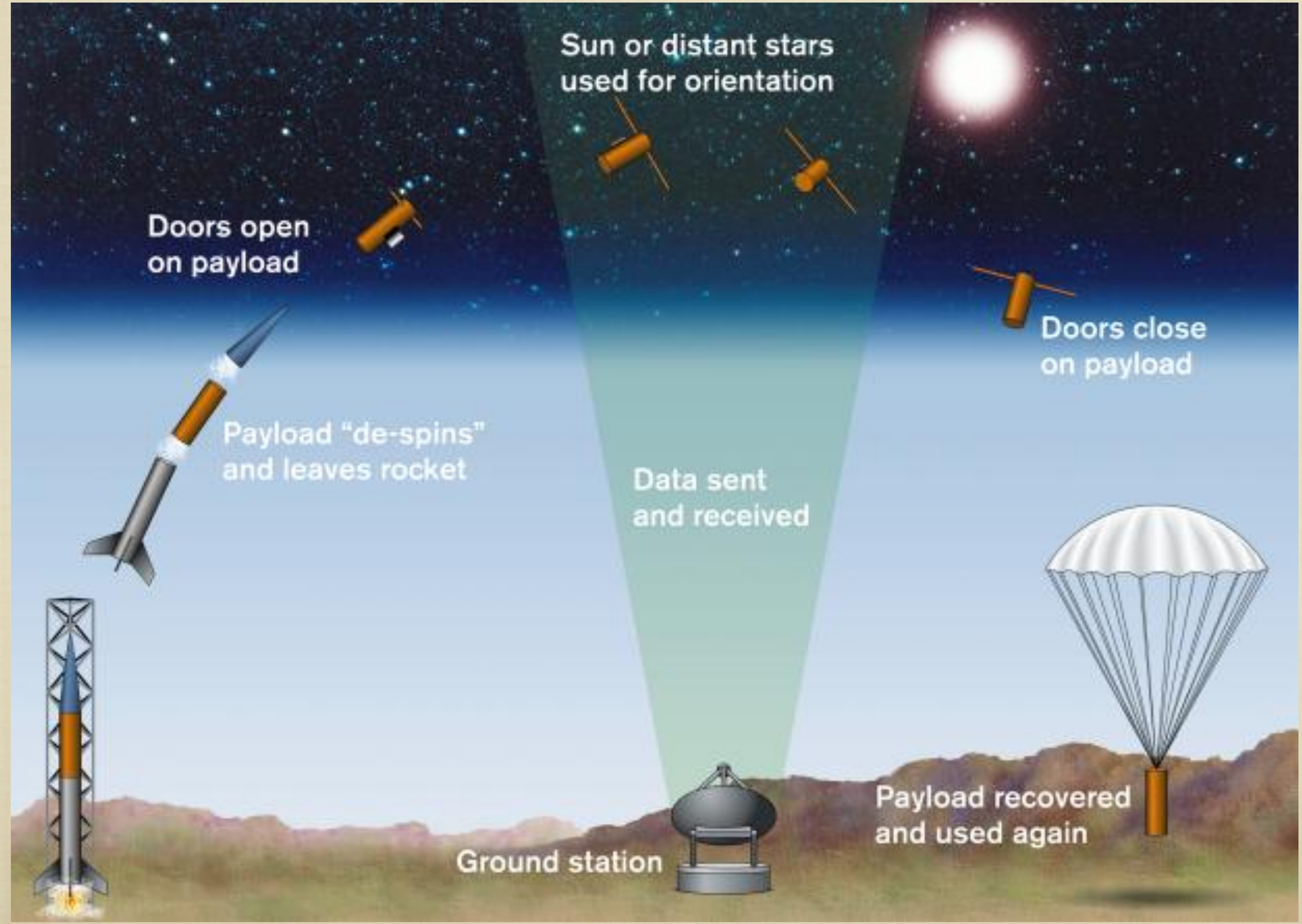
How to build a Sounding Rocket Instrument

- Step 1 – Propose (Can take several years to write a winning proposal)
  - Nasa receives 30+ proposals each year, selects 1-2.
- Step 2 – Build an instrument (3-4 years)
- Step 3 – Launch (1 month in the field + 5 minutes! in the air)

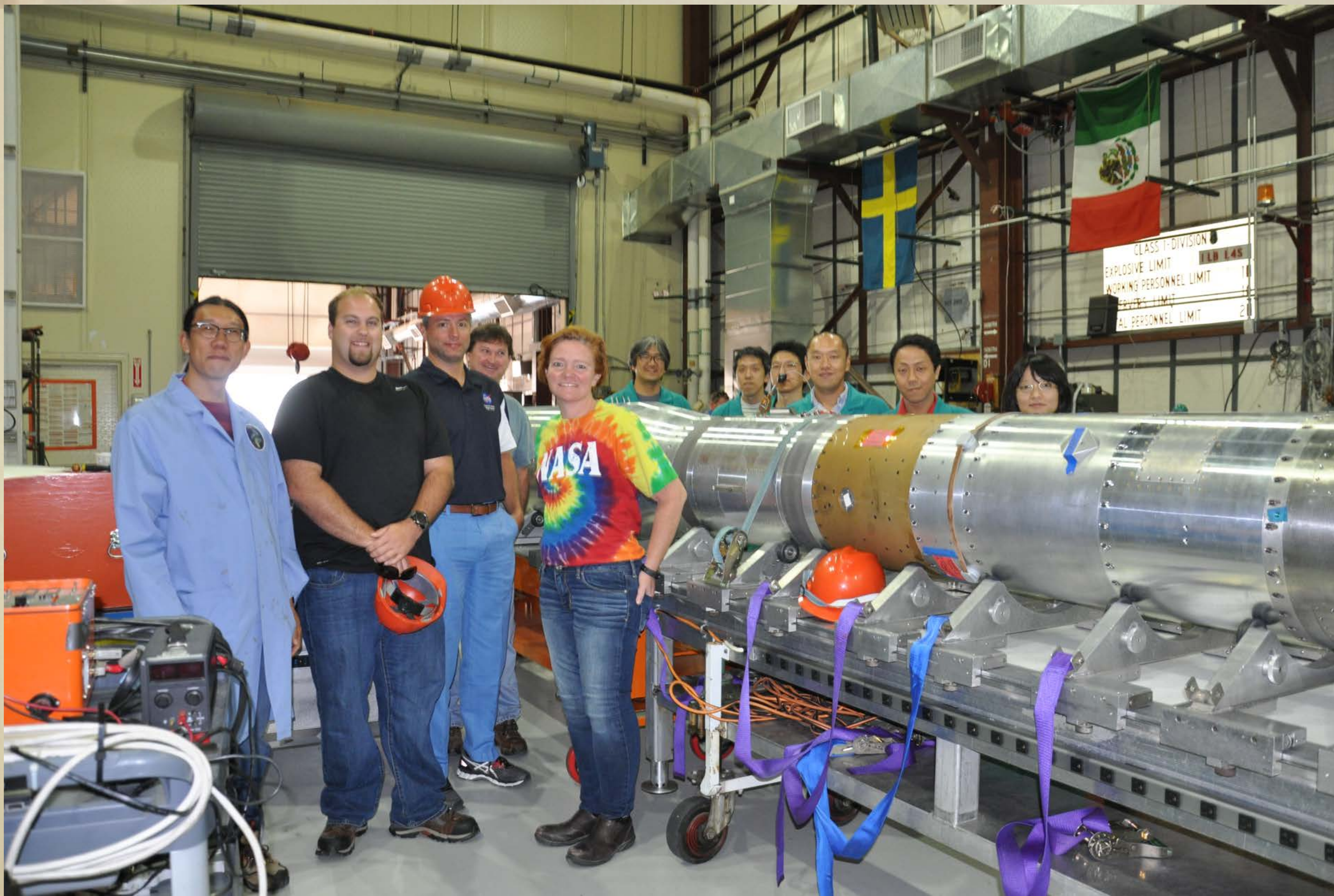
The Make up of a Sounding Rocket



The Flight of a Sounding Rocket

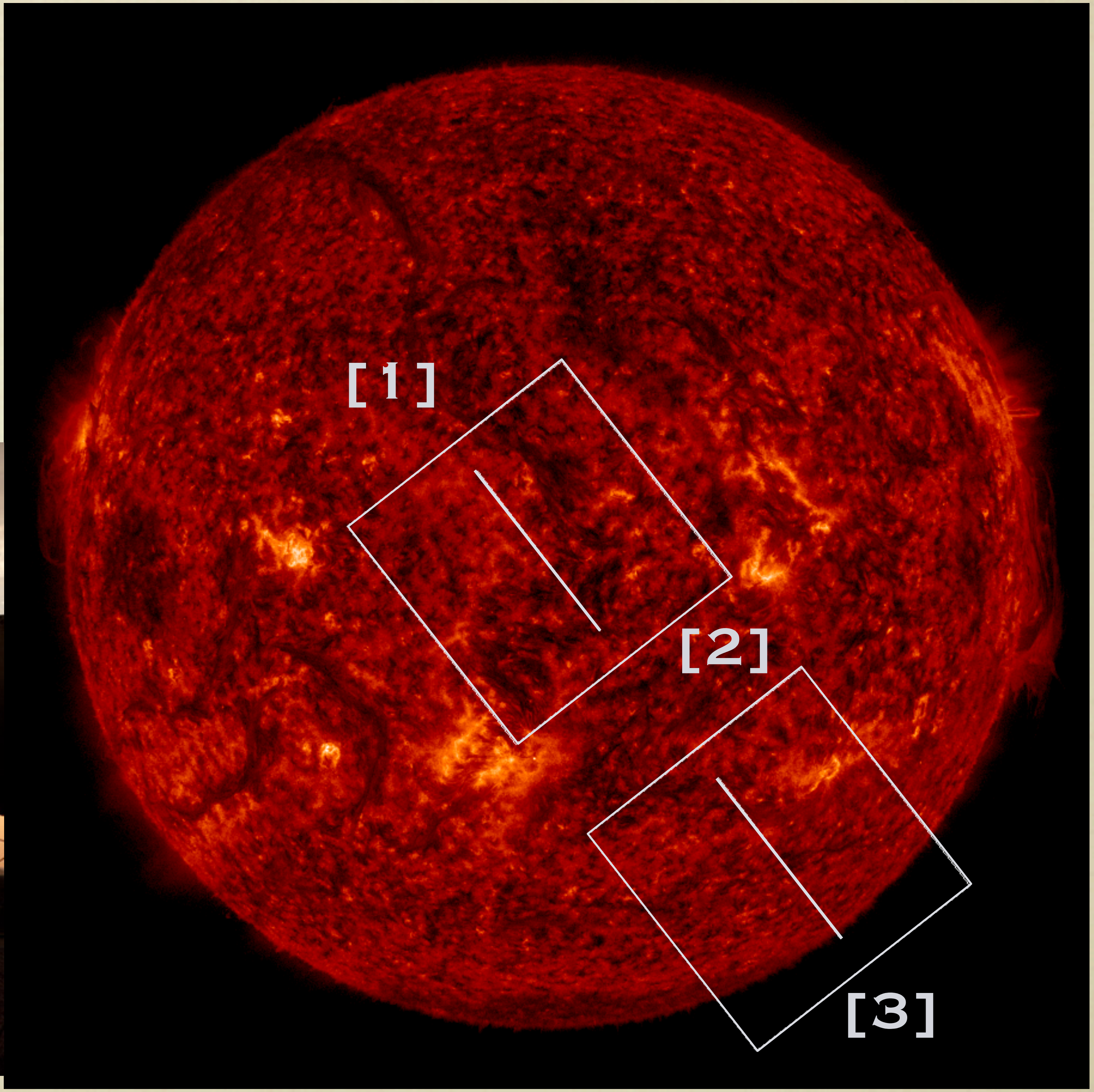


Life at White Sands

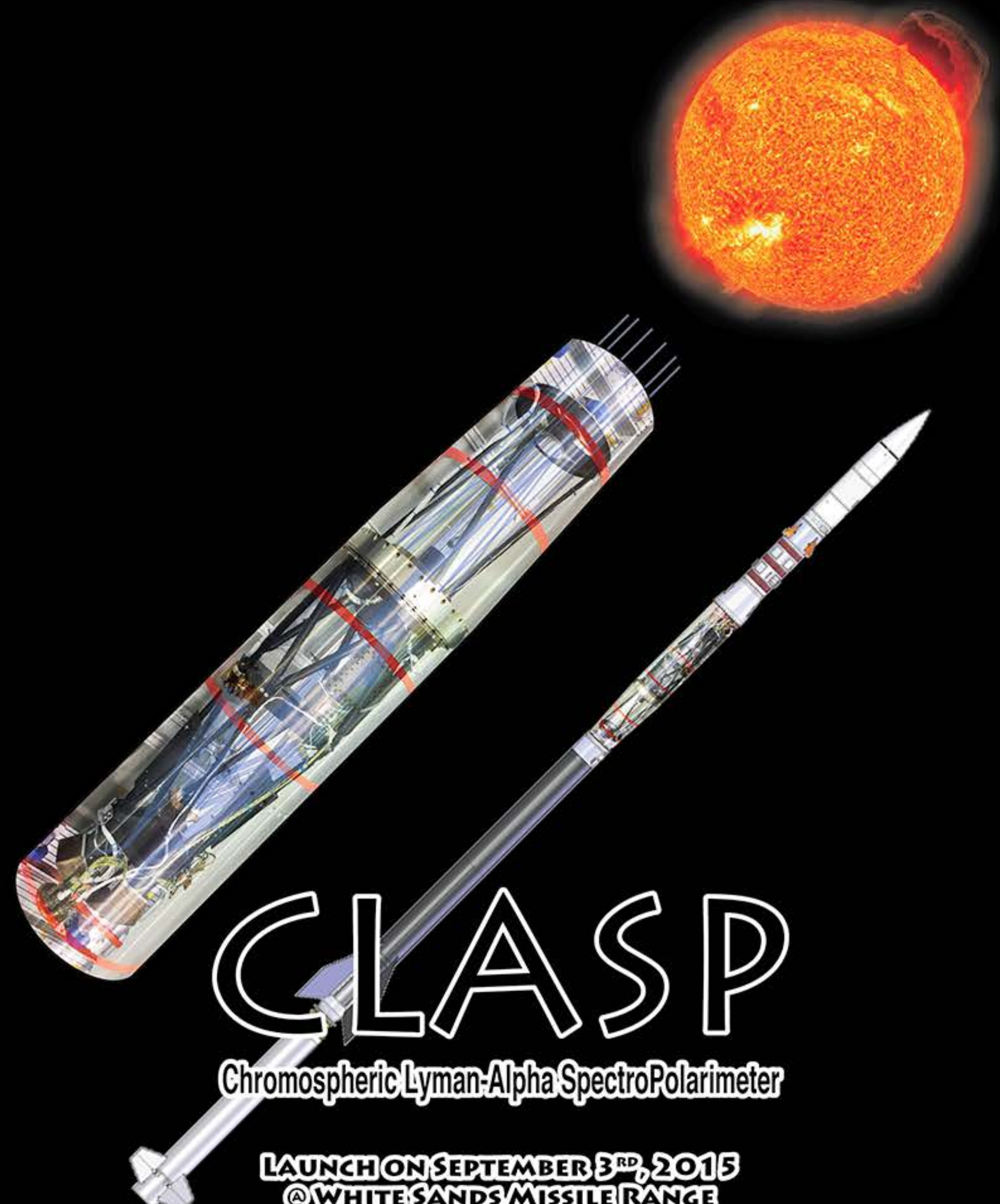


Launch day!

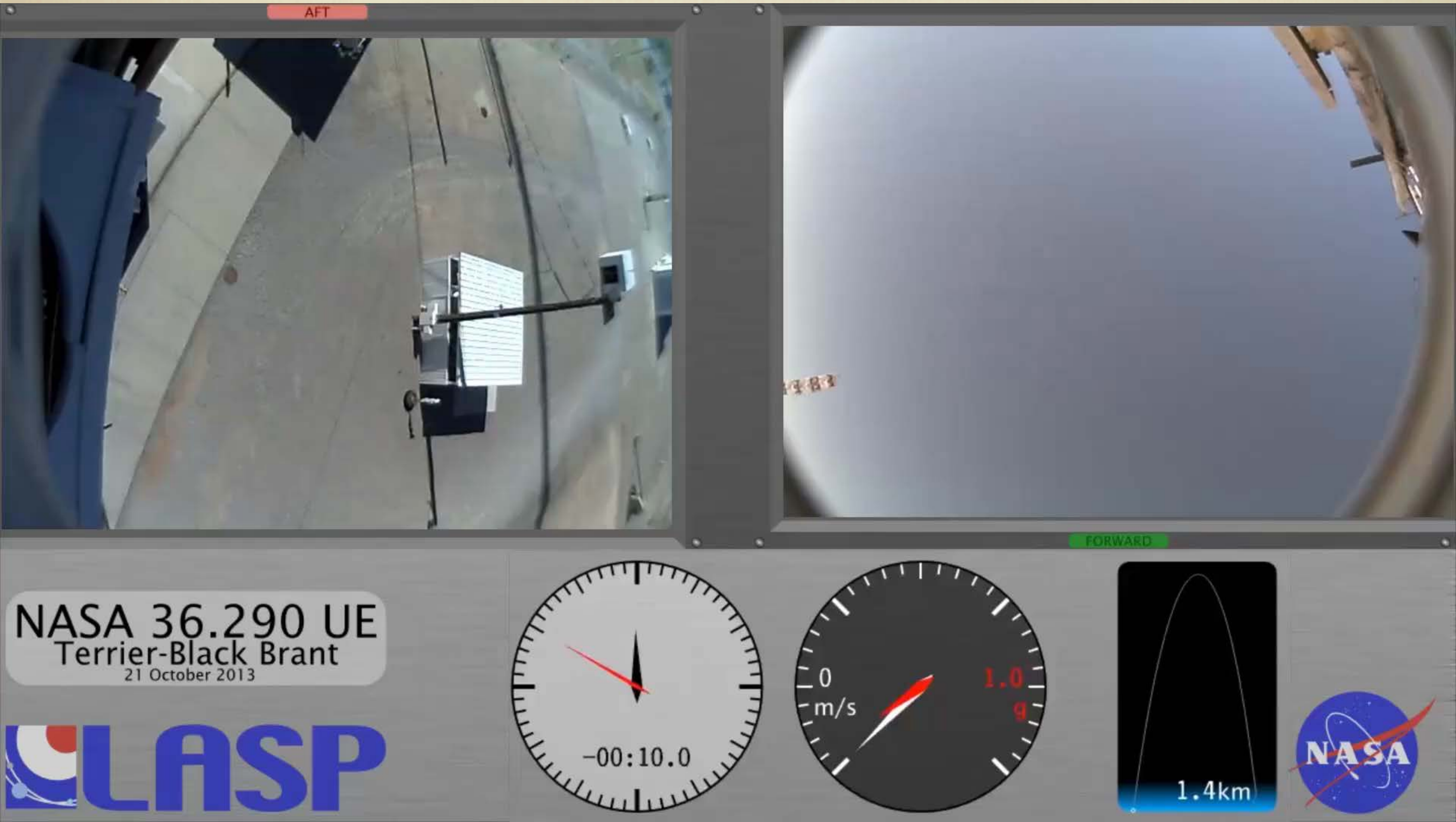
CLASP was launched on September 3, 2015 from White Sand Missile Range



Chromospheric Lyman-Alpha Spectropolarimeter (CLASP)



Launch from the Rocket's Perspective



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- ✓ What is the NASA Sounding Rocket program?
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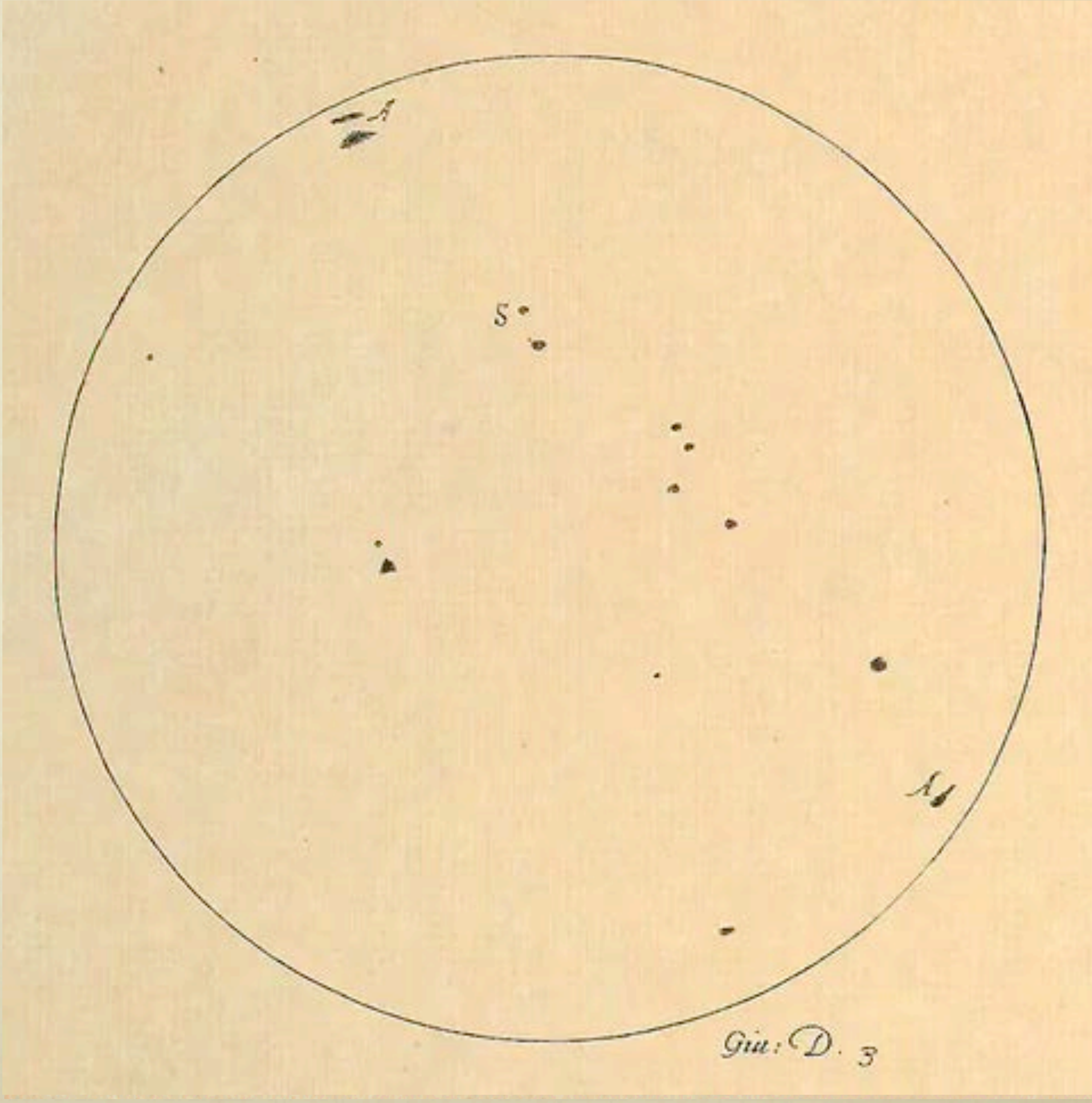
Background

What does the Sun look like?

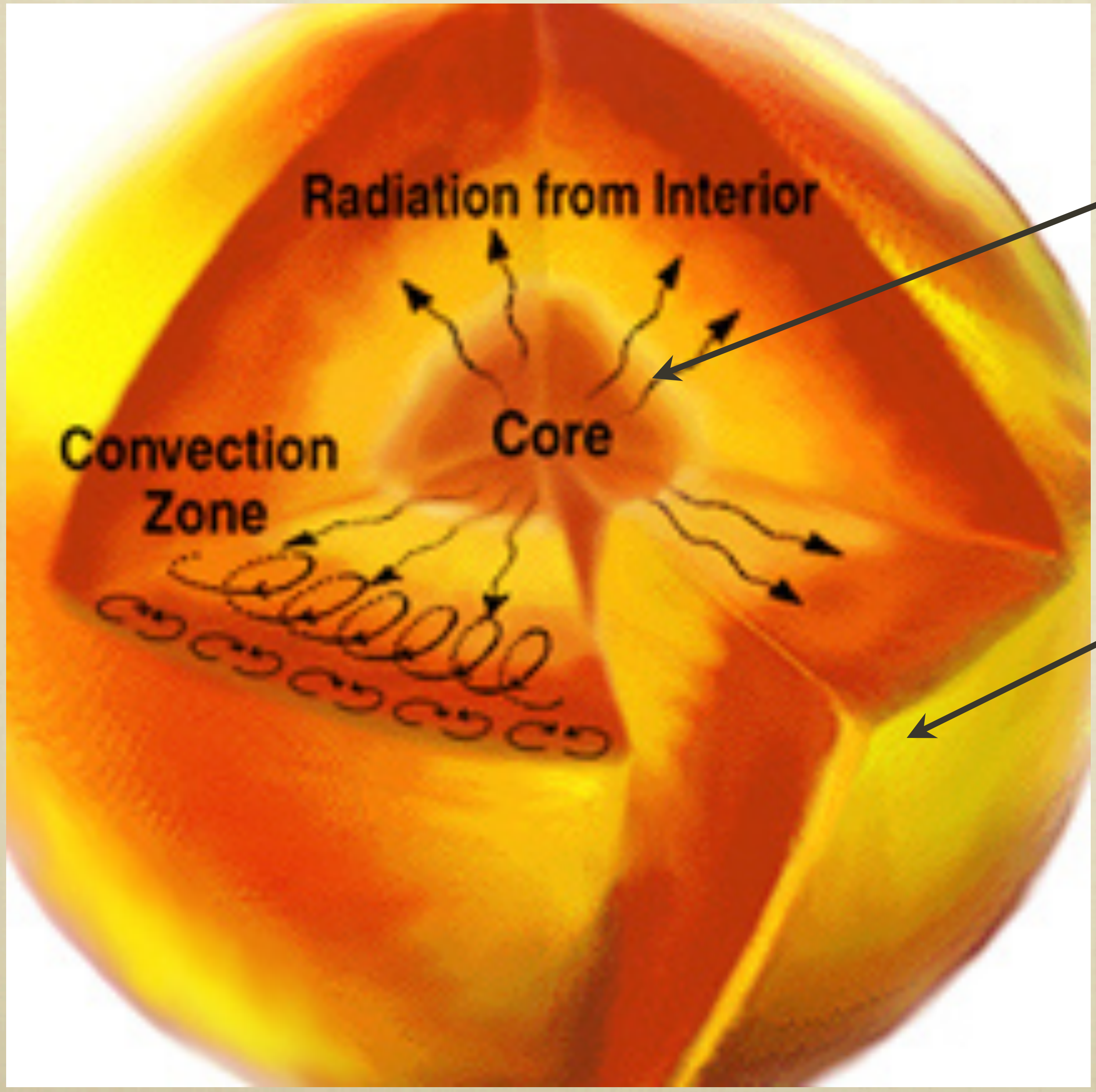
Galileo drew the Sun at the same time each day.
His drawings reveal "sunspots," dark areas on the Sun.

Now we know sunspots are strong magnets on the Sun.



Background

What is the temperature of the Sun?

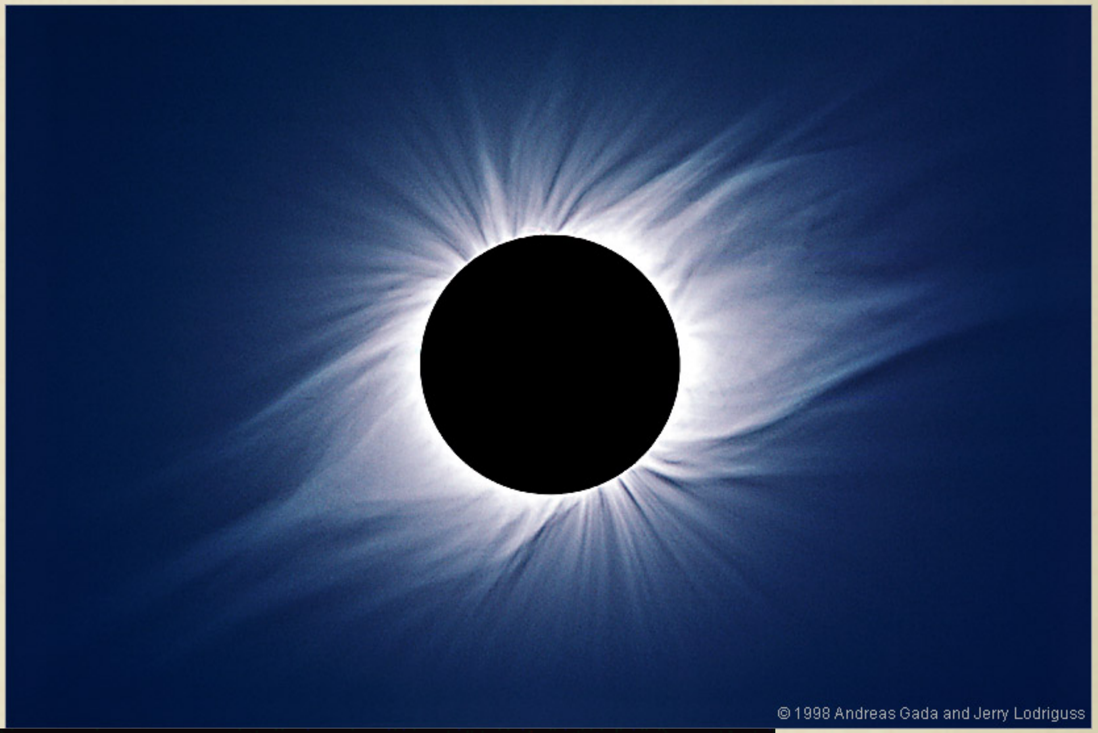


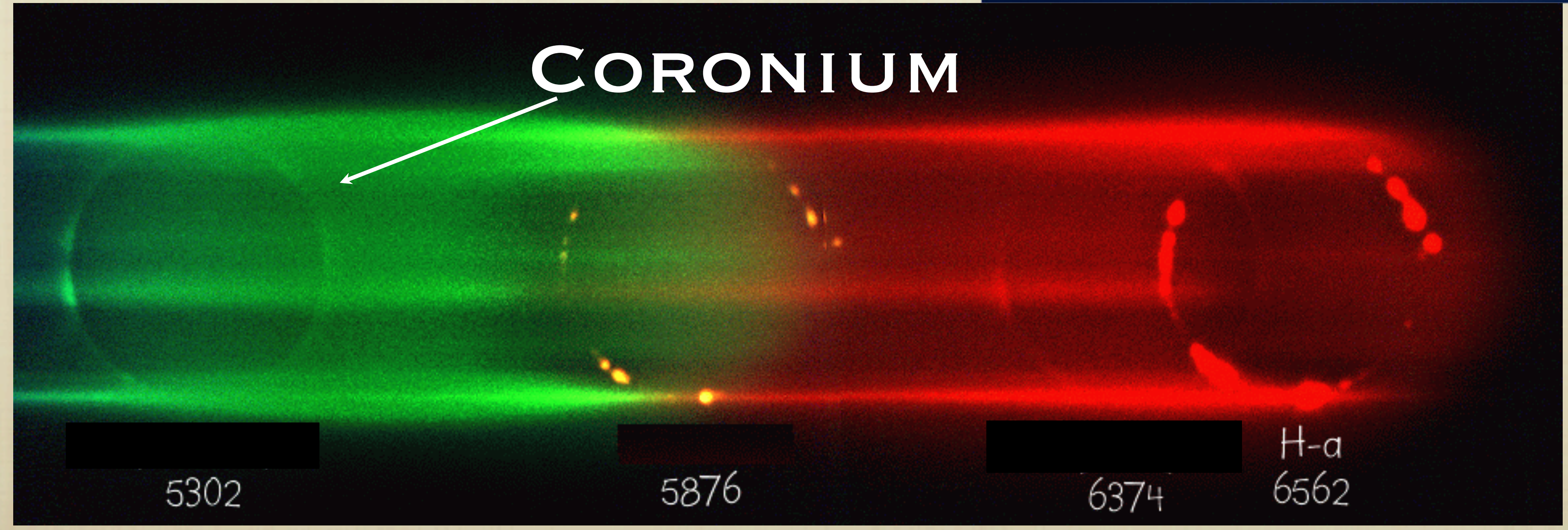
22 MK in core

5,000 K on Surface

Background

- In the mid-1800s, spectral observations of solar corona during eclipse discovered a spectral line from unknown element - "Coronium"





Background

- In the 1930s, Gotrian and Edlen discovered the 5303 line was from Fe XIV implying the solar corona contained million degree plasma.

- Originally, the atmosphere was treated as "plane parallel", meaning the temperature and density of the corona depend only on the distance from the solar surface

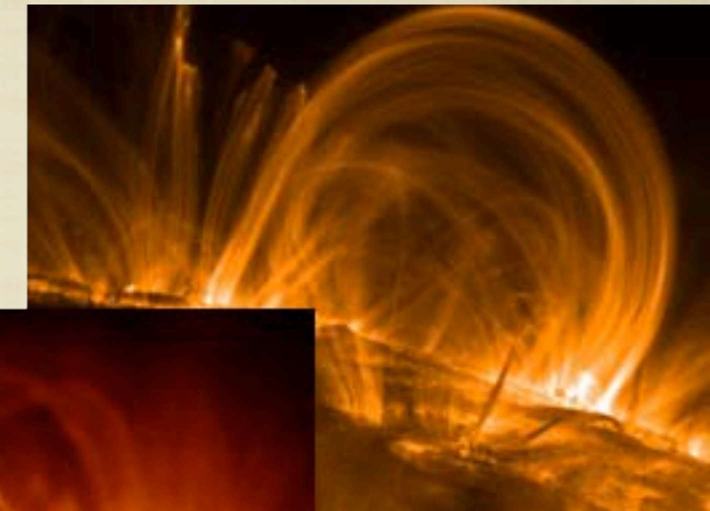
Background

First X-ray Image
of the Sun
April 19, 1960

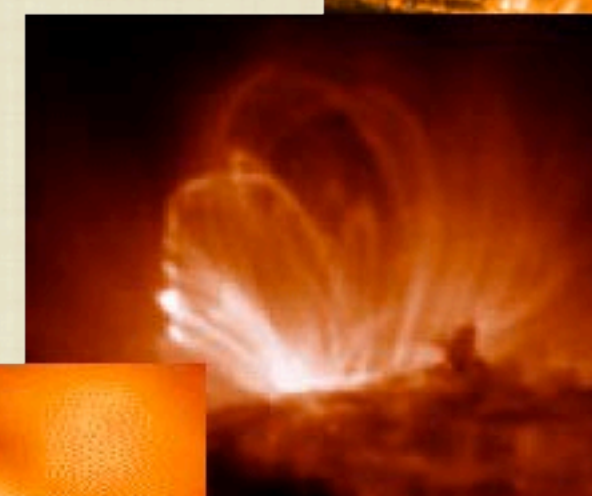
Background

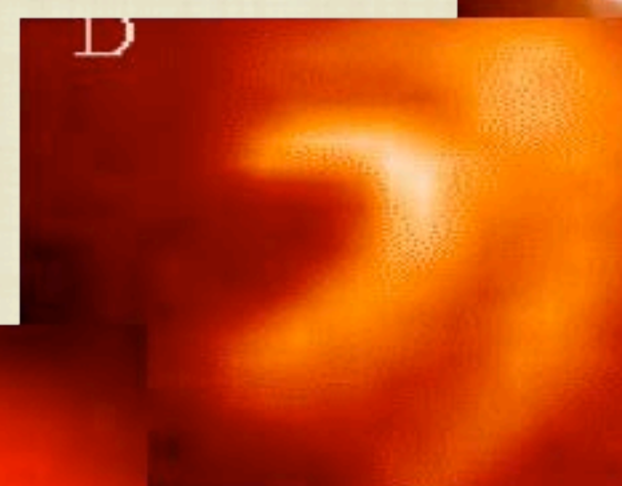
Improvements in Spatial resolution led to finer and finer structures

Trace 1999



SOHO EIT 1996

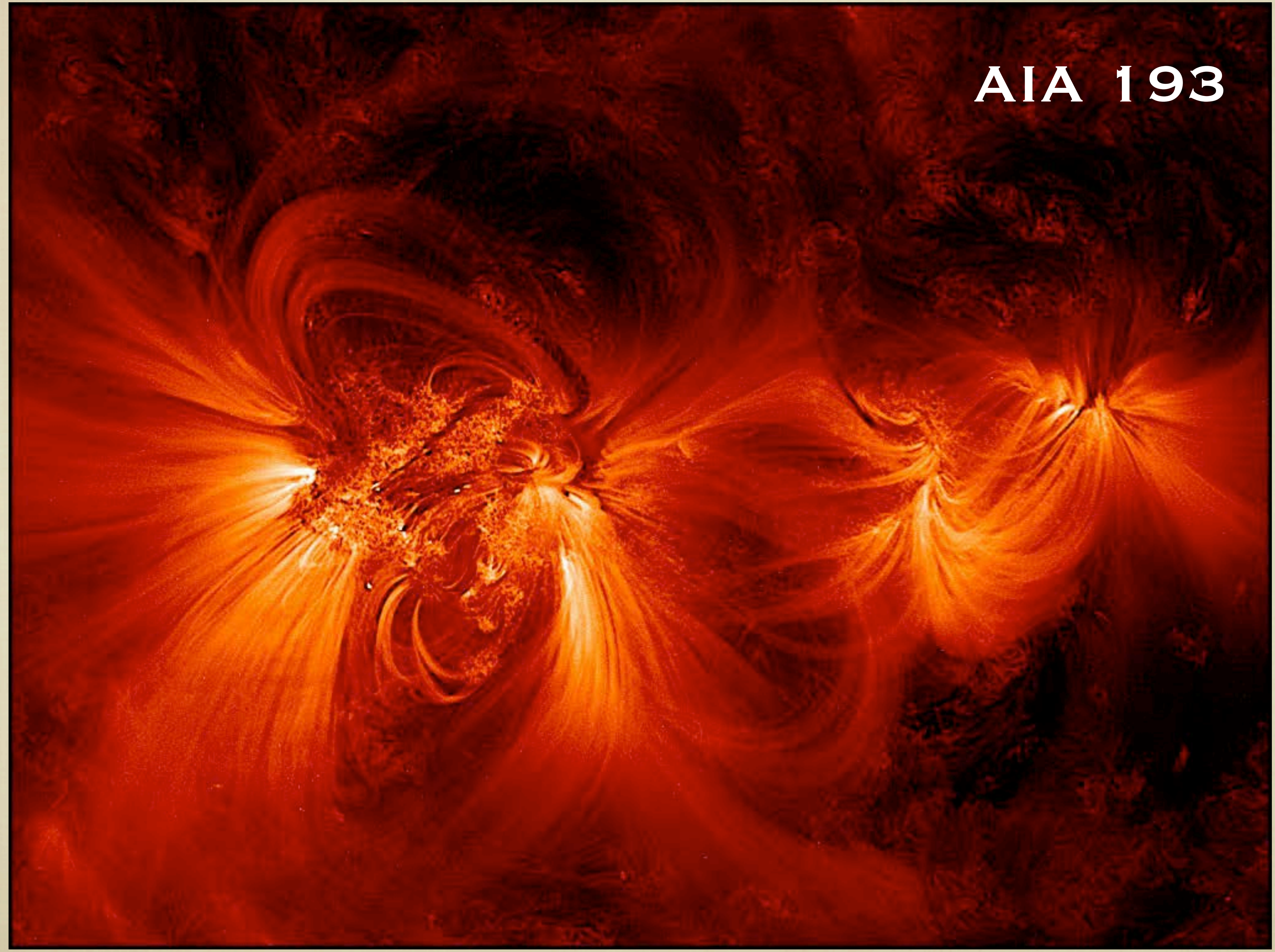




Yohkoh 1982

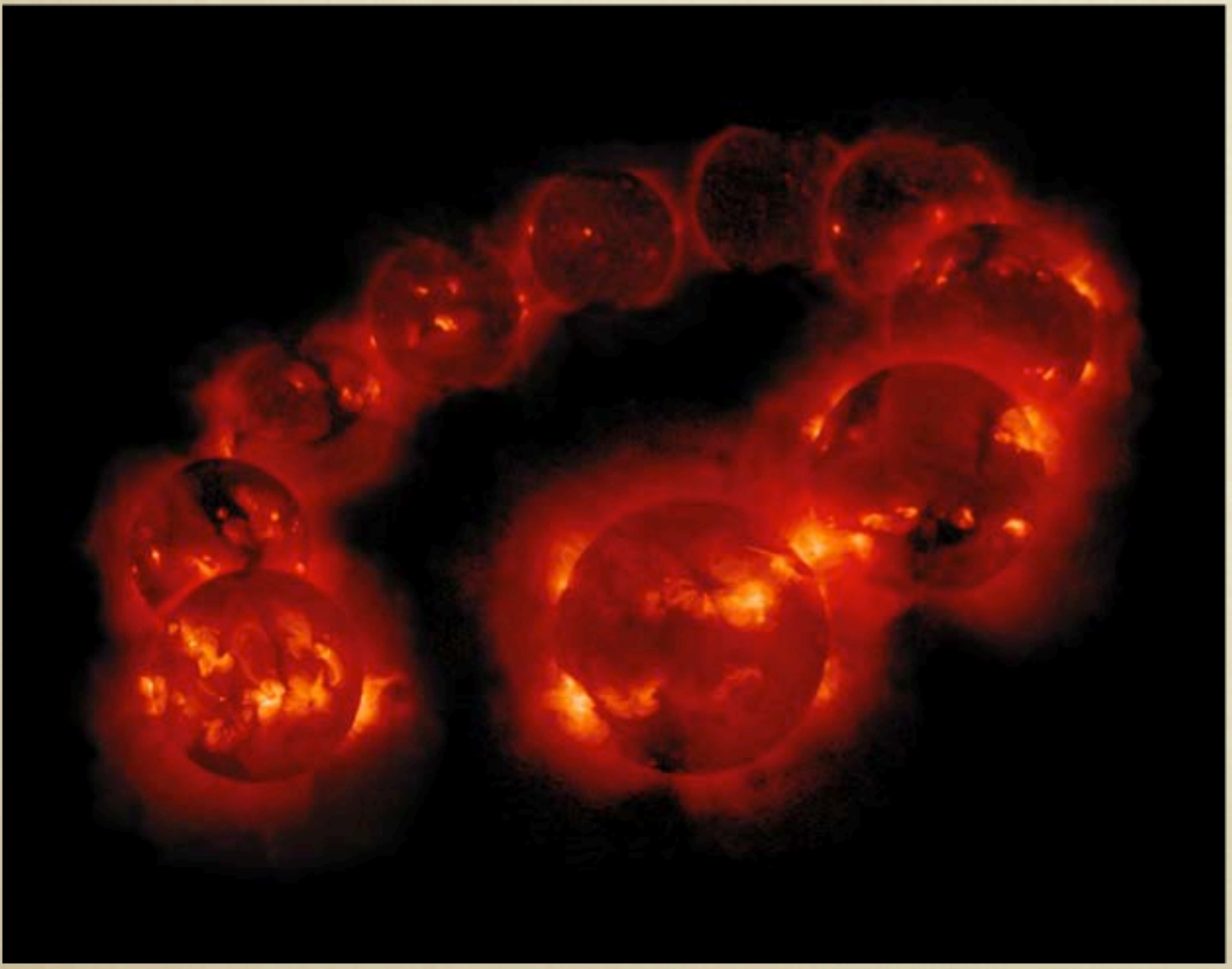
Skylab 1973

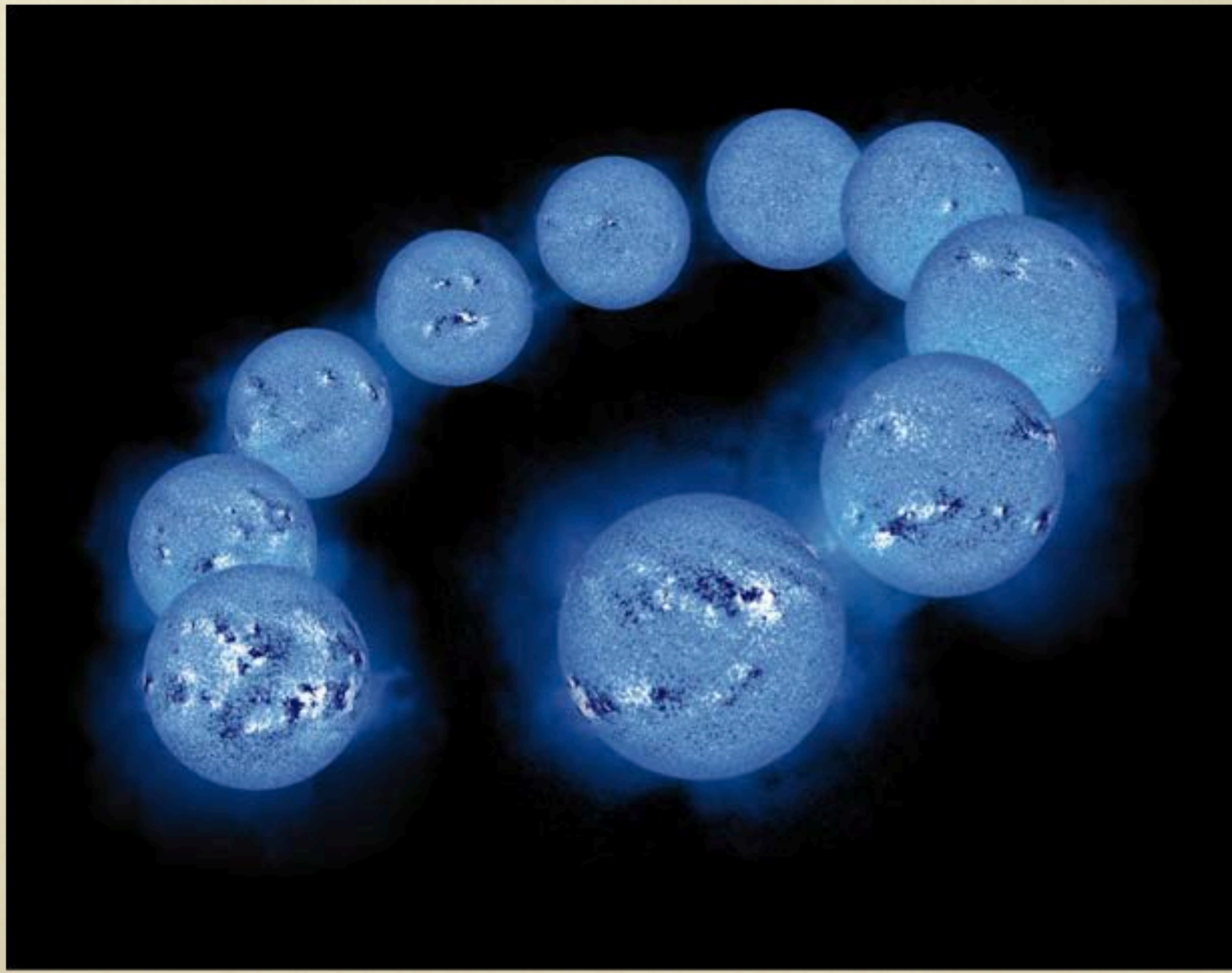
Background



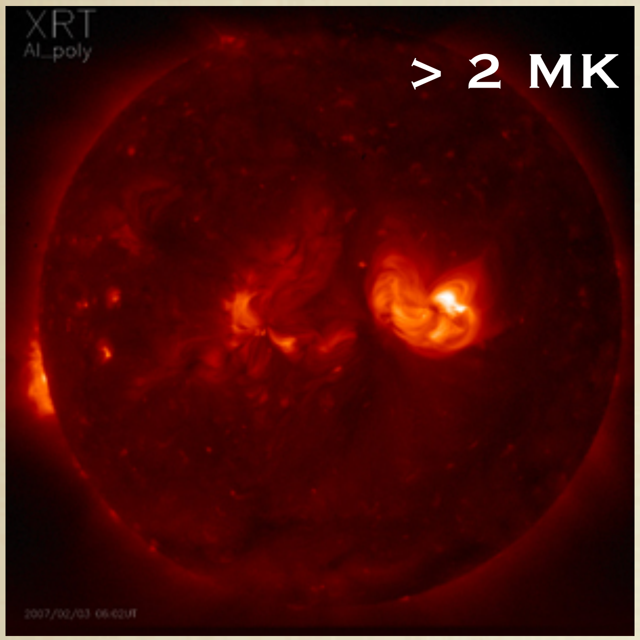
Background

There is more hot plasma in times of strong magnetic field.

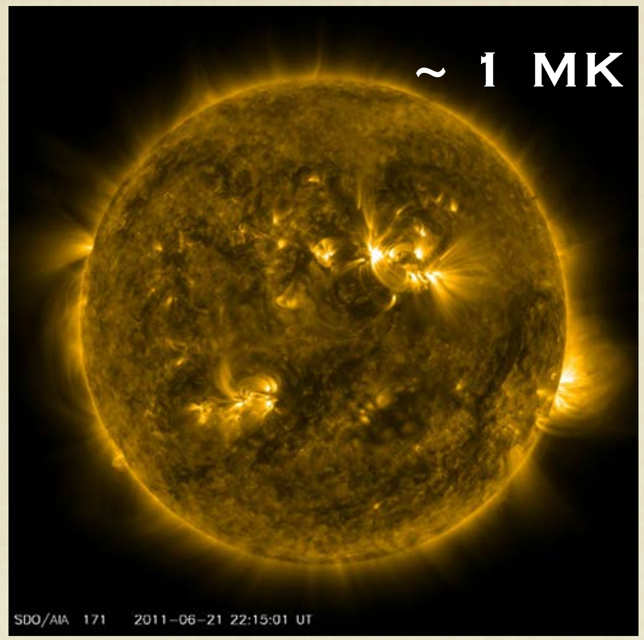




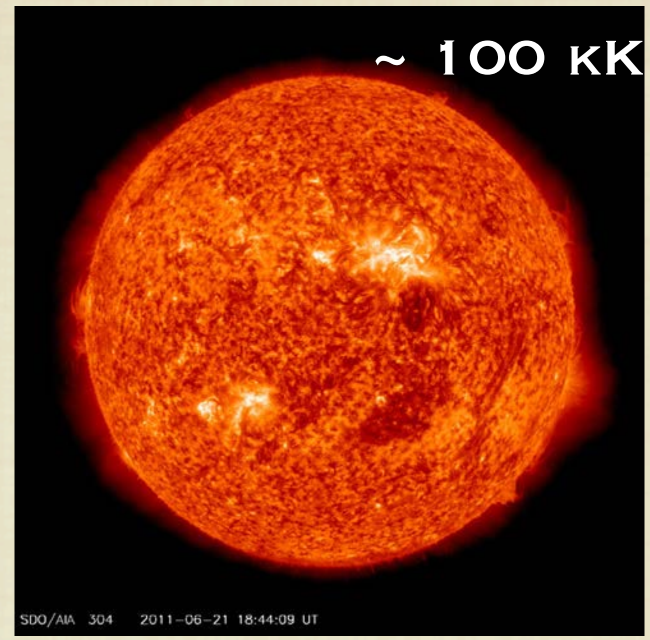
Background



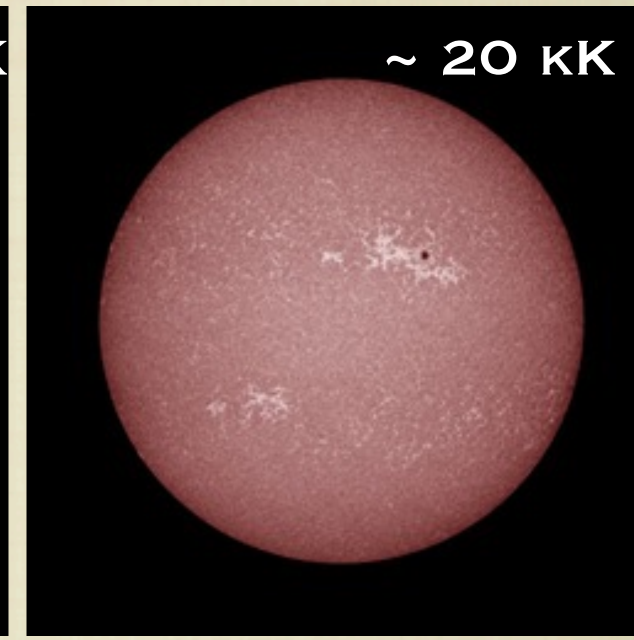
X-ray



EUV

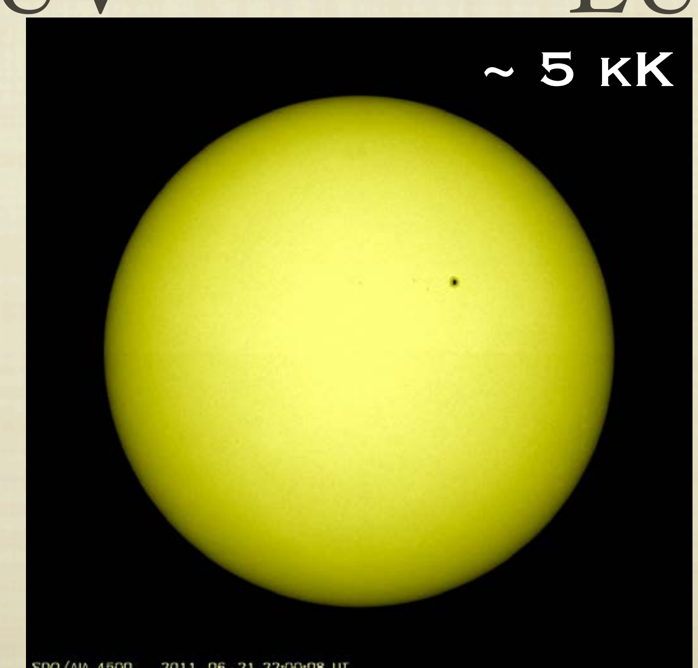


EUV



FUV

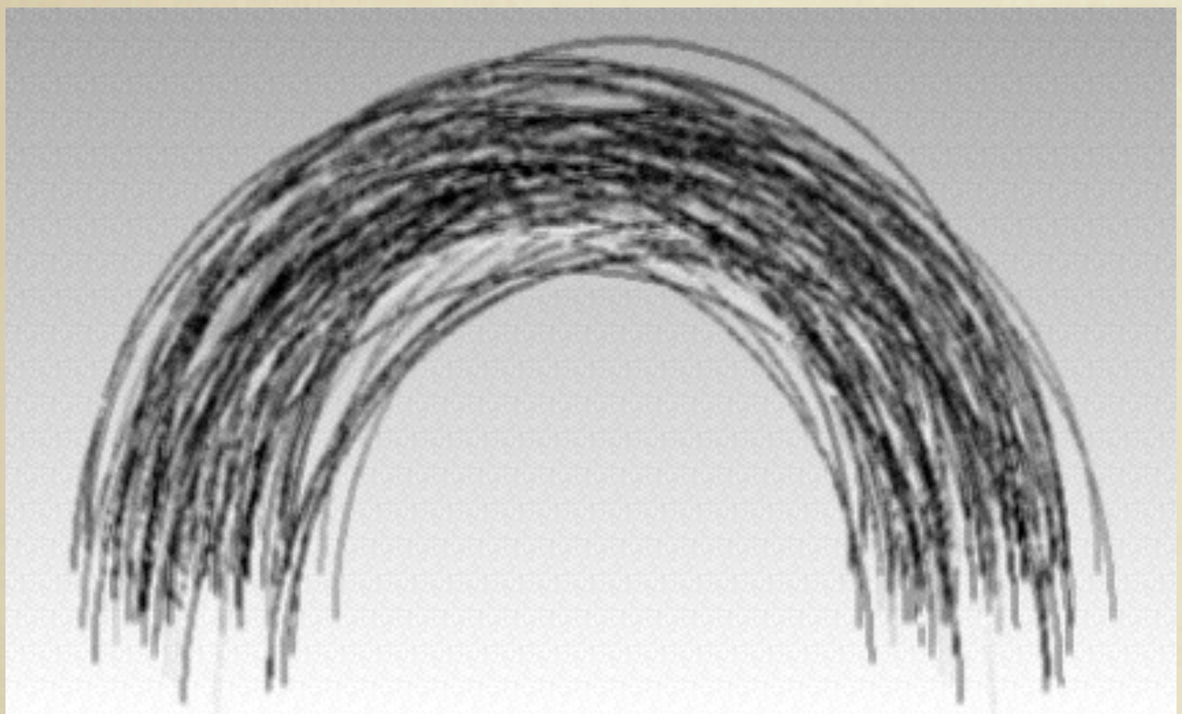
When we take images of the Sun in different wavelengths, we see different structures



White Light

Different wavelengths show different temperatures.

Background



Strand - Fundamental coronal structure

Loop - Observed coronal structure

If number of strands/loop = 1, we are resolving the corona.

Coronal Heating Theories

Many different theories for carrying and dissipating energy in the corona

TABLE 5

Summary of the Scaling Law for Different Models of Coronal Heating

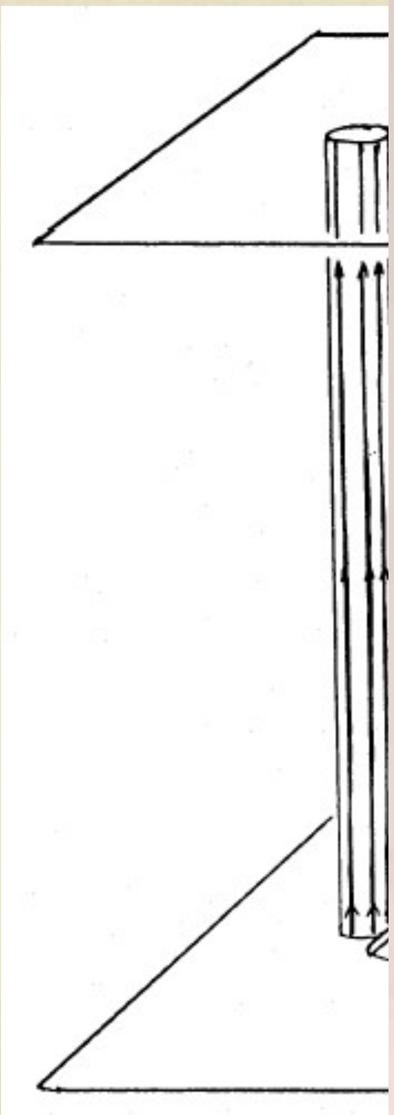
Model Characteristics	N^0	References	Scaling Law	Parameters
Stressing Models (DC)				
Stochastic buildup	1	1	$B^2L^{-2}V^2\tau$	
Critical angle	2	2	$B^2L^{-1}V \tan \theta$	
Critical twist	3	3	$B^2L^{-2}VR\phi$	
Reconnection $\propto v_A$	4	4	$BL^{-2}\rho^{1/2}V^2R$	
Reconnection $\propto v_{A\perp}$	5	5	$B^{3/2}L^{-3/2}\rho^{1/4}V^{3/2}R^{1/2}$	
Current layers	6	6	$B^2L^{-2}V^2\tau \log R_m$	
	7	7	$B^2L^{-2}V^2\tau S^{0.1}$	
	8	8	$B^2L^{-2}V^2\tau$	
Current sheets	9	9	$B^2L^{-1}R^{-1}V^2_{\mathrm{ph}}\tau$	
Taylor relaxation	10	10	$B^2L^{-2}V^2_{\mathrm{ph}}\tau$	
Turbulence with:				
Constant dissipation coefficients	11	11	$B^{3/2}L^{-3/2}\rho^{1/4}V^{3/2}R^{1/2}$	
Closure	12	12	$B^{5/3}L^{-4/3}\rho^{1/6}V^{4/3}R^{1/3}$	
Closure + spectrum	13	13	$B^{s+1}L^{-1-s}\rho^{(1-s)/2}V^{2-s}R^s$	$s = 0.7, m = -1$
	14			$s = 1.1, m = -2$
Wave Models (AC)				
Resonance	15	14	$B^{1+m}L^{-3-m}\rho^{-(1+m)/2}$	$m = -1.$
	16			$m = -2.$
Resonant absorption	17	15	$B^{1+m}L^{-1-m}\rho^{-(1+m)/2}$	$m = -1.$
	18			$m = -2.$
	19	16	$B^{1+m}L^{-m}\rho^{-(m-1)/2}$	$m = -1.$
	20			$m = -2.$
Current layers	21	17	$BL^{-1}\rho^{1/2}V^2$	
Turbulence	22	18	$B^{5/3}L^{-4/3}R^{1/3}$	

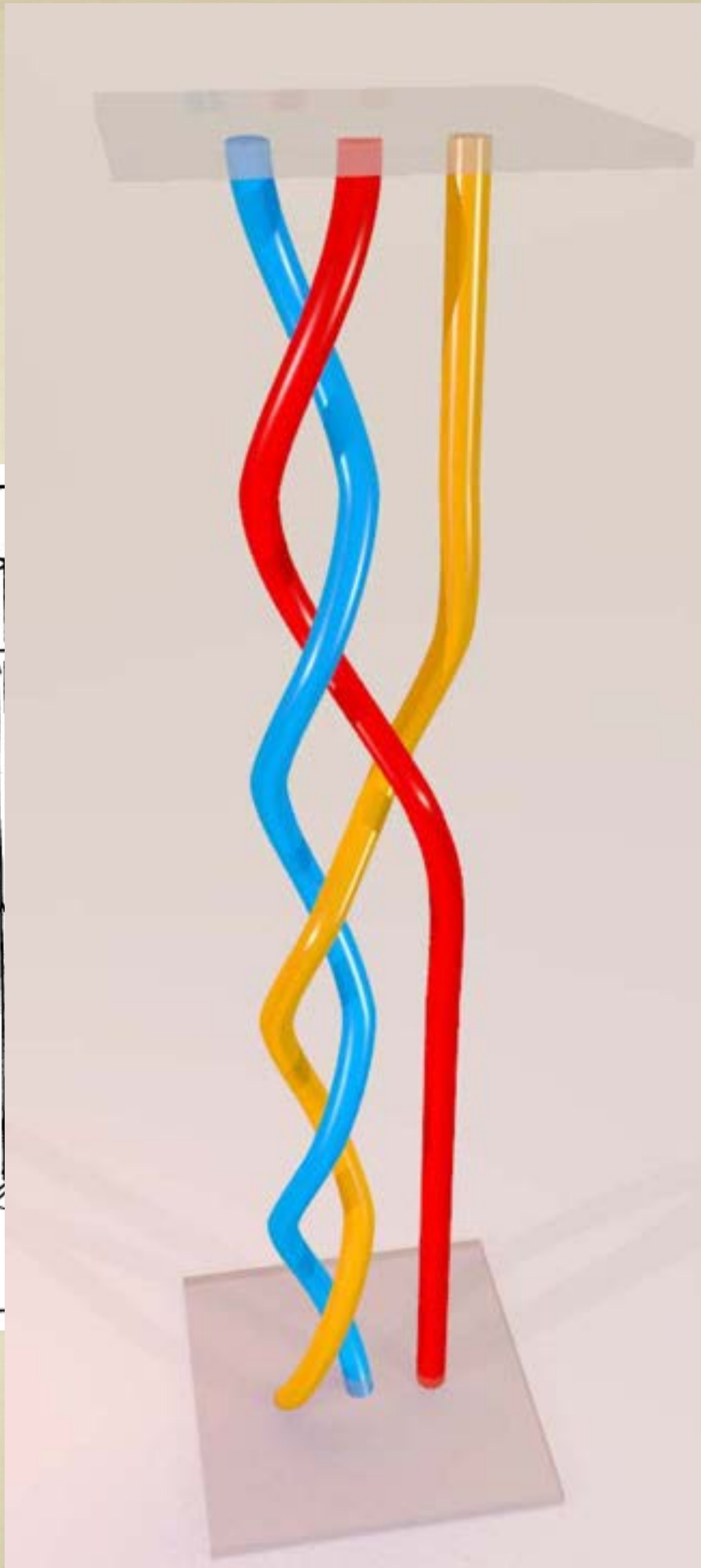
References.—(1) Sturrock & Uchida 1981, Berger 1991; (2) Parker 1988, Berger 1993; (3) Galsgaard & Nordlun 1997; (4) Parker 1983; (5) Parker 1983, modified; (6) van Ballegooijen 1986; (7) Hendrix et al. 1996; (8) Galsgaard Nordlund 1996; (9) Aly & Amari 1997; (10) Heyvaerts & Priest 1984, Browning & Priest 1986, Vekstein et al. 1993; (1 Einaudi et al. 1996, Dmitruk & Gómez 1997; (12) Heyvaerts & Priest 1992, Inverarity et al. 1995, Inverarity & Prie 1995a; (13) Milano et al. 1997; (14) Hollweg 1985; (15) Ofman et al. 1995, Ruderman et al. 1997; (16) Halberstadt Goedbloed 1995; (17) Galsgaard & Nordlund 1996; (18) Inverarity & Priest 1995b.

Mandrini et al, ApJ 2000

Nanoflare

- Parker suggested braiding of the magnetic field by photospheric motions would drive small-scale coronal reconnection

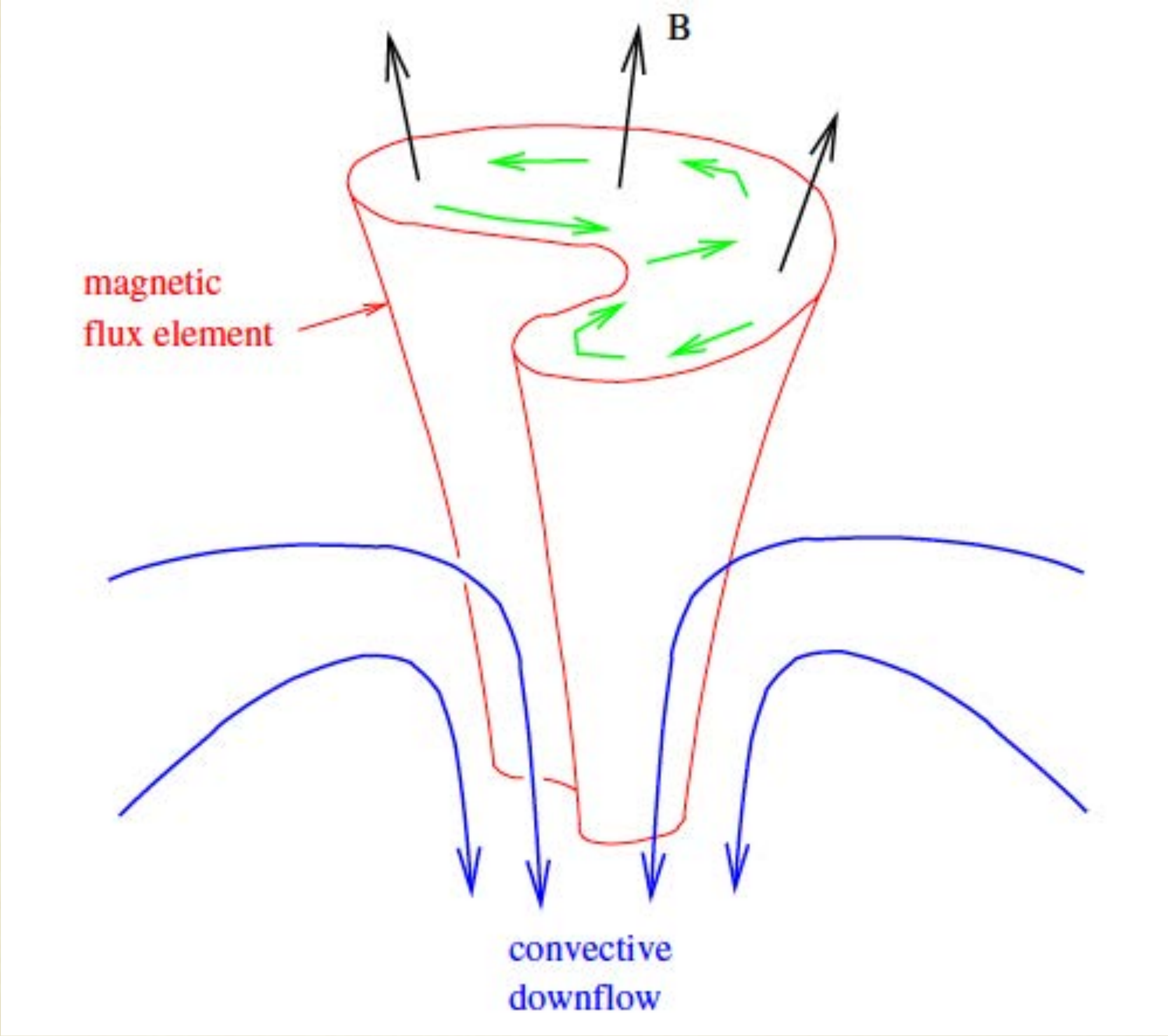




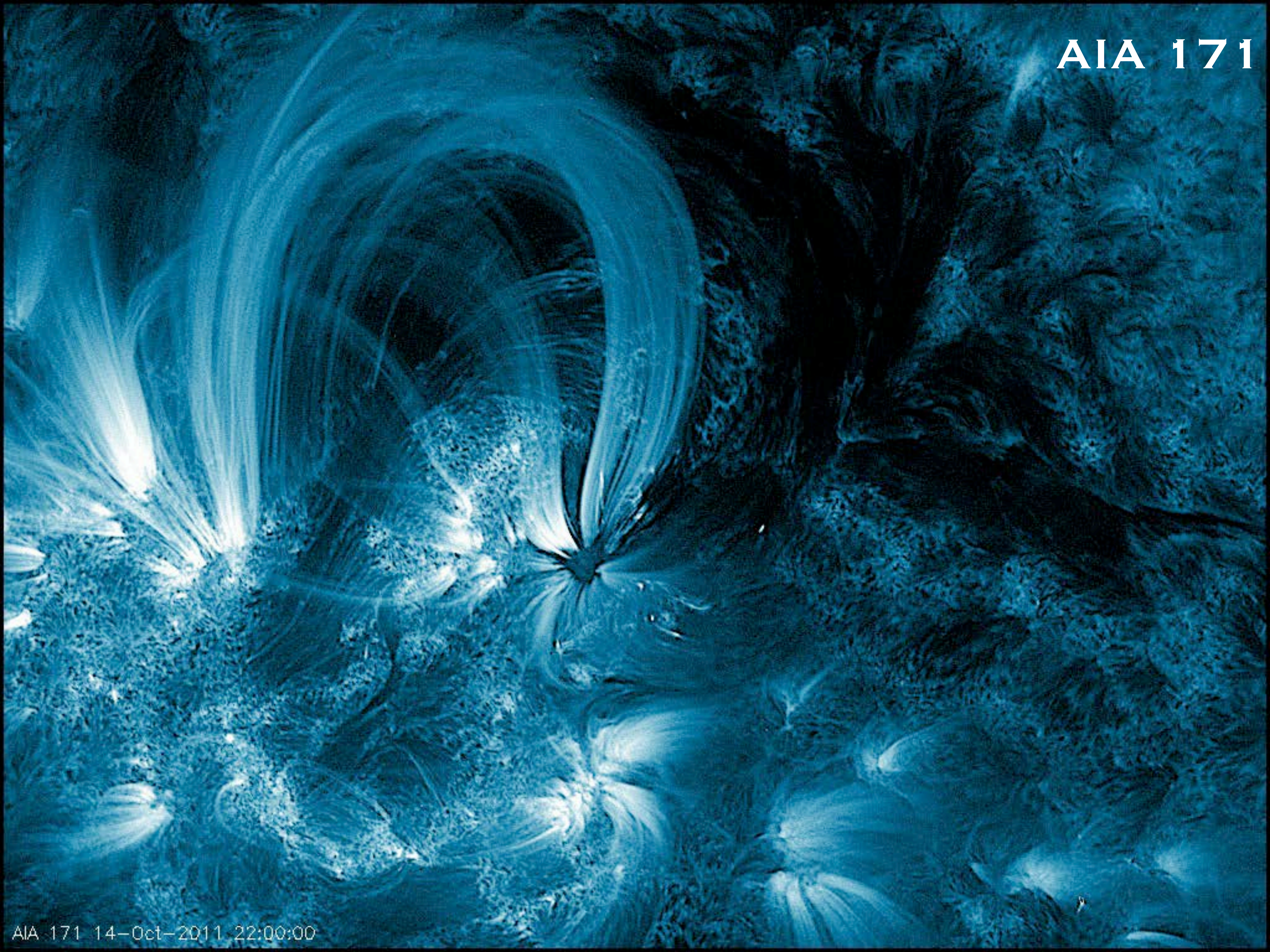

AIA 171
No evidence of Coronal Braiding
AIA 171 15-Apr-2011 00:15:00

Waves

Alfven Waves dissipated by turbulence

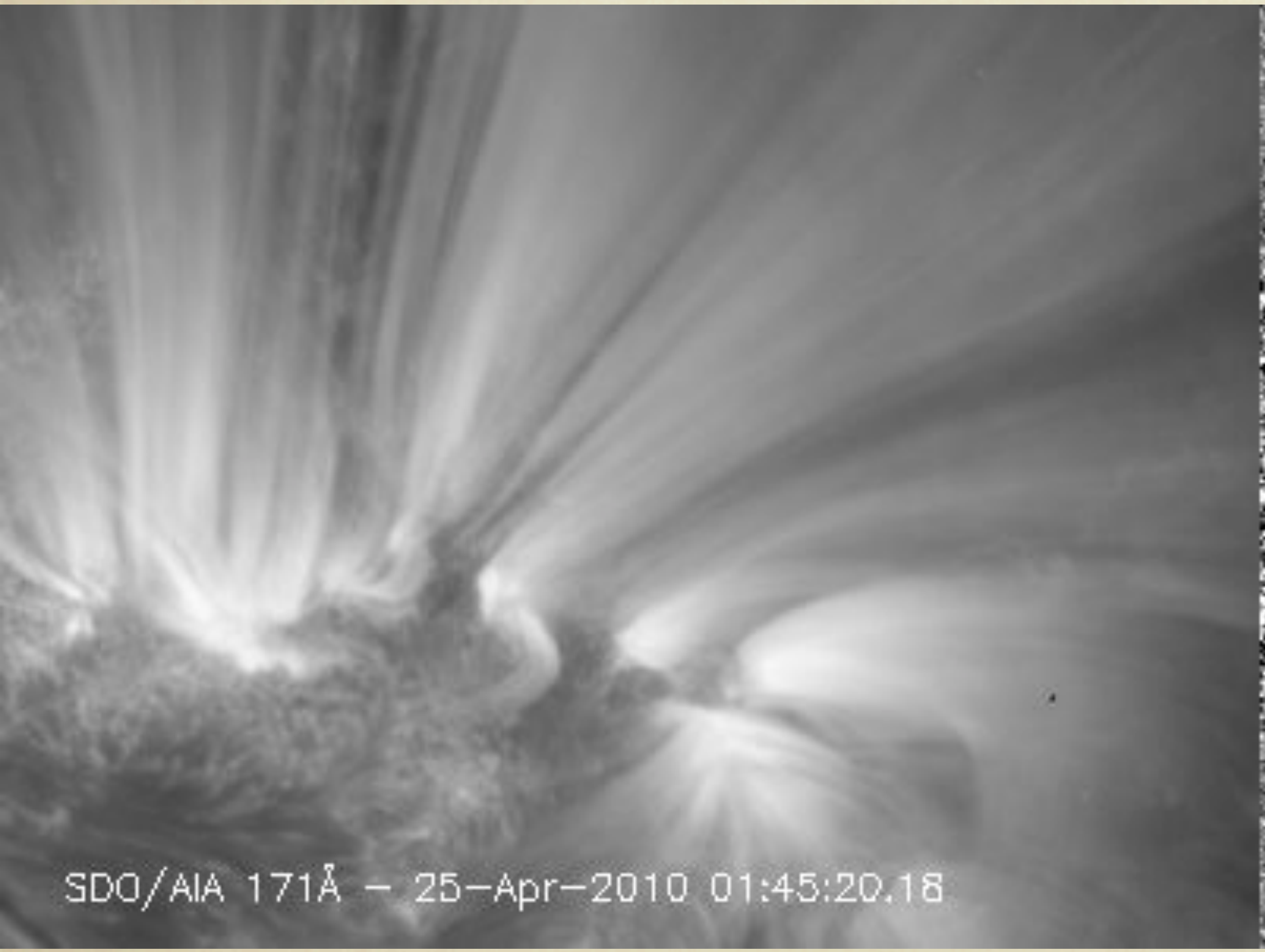


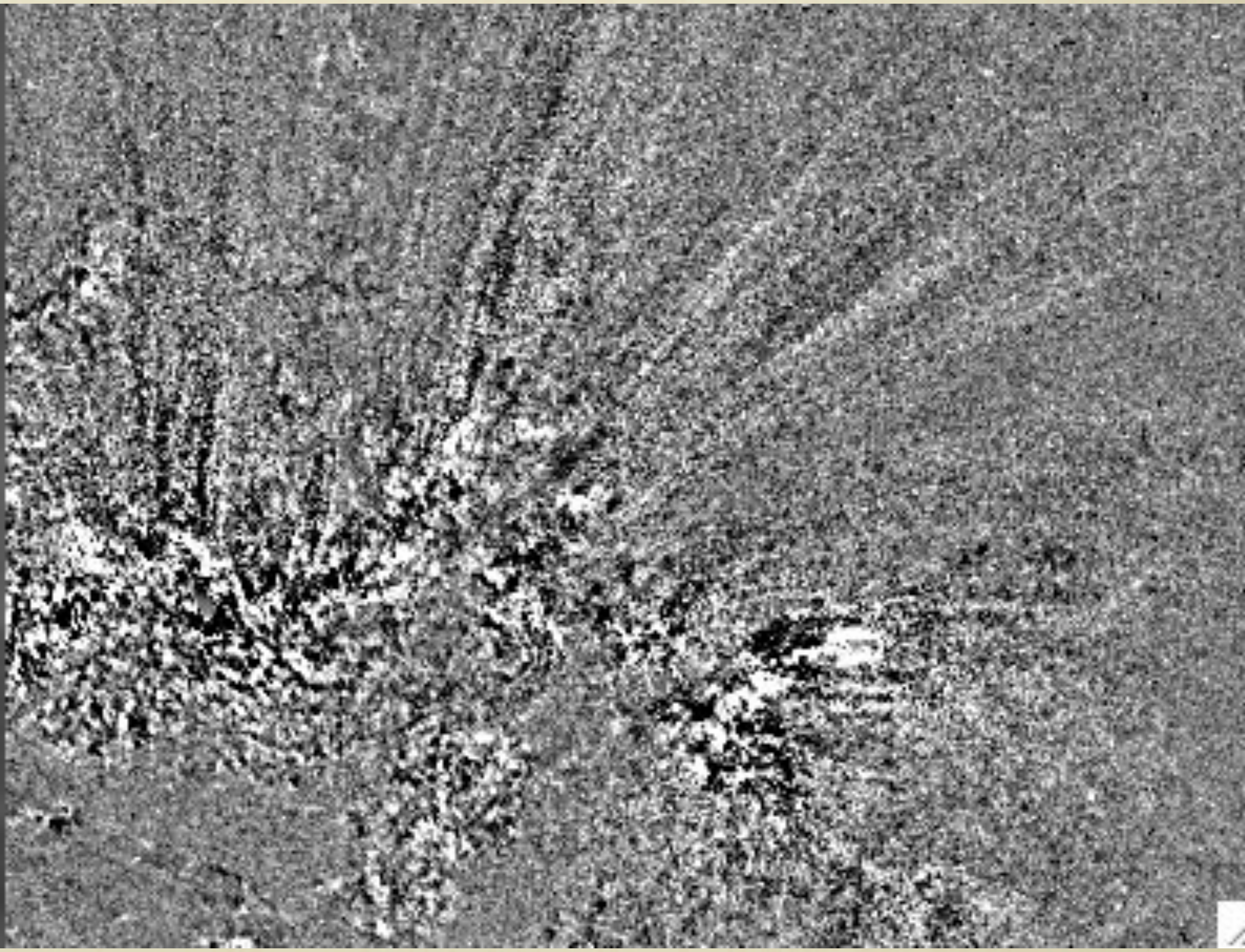
van Ballegooijen, et al. ApJ 2011


AIA 171
AIA 171 14-Oct-2011 22:00:00

Waves are ubiquitous

Waves are simply everywhere, but is there enough energy to heat the corona?





Scott McIntosh

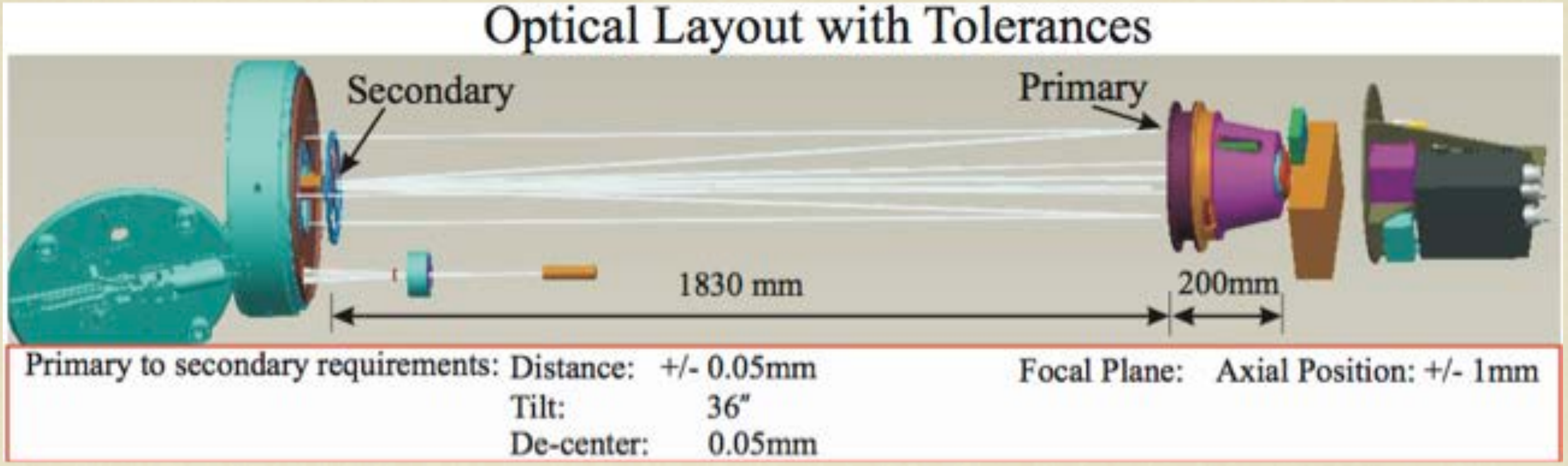
The Problem

Nanoflares can release enough energy to heat the corona, but braided structures have never been observed.

Waves have been observed, but may not have enough energy to heat the corona.

The Solution? Launch a new Sounding Rocket Instrument!

High-resolution Coronal Imager (Hi-C)



- Images the sun in the 193 A passband (EUV, 1.5 MK)

- Spatial resolution is 36x that of other instruments

Hi-C Partner Institutions

NASA Marshall Space Flight Center (MSFC)
University of Alabama – Huntsville (UAH)
Smithsonian Astrophysical Observatory (SAO)
University of Central Lancashire, UK (UCLAN)
Lockheed Martin Solar and Astrophysical Laboratory (LMSAL)
Southwest Research Institute (SWRI)
Lebedev Institute (LI)

Hi-C Team Members

Jonathan Cirtain, PI (MSFC)

Science Team:
Leon Golub (SAO)
Ken Kobayashi (UAH)
Kelly Korreck (SAO)
Robert Walsh (UCLAN)
Amy Winebarger (MSFC)
Bart DePontieu (LMSAL)
Craig Deforest (SWRI)
Sergey Kuzin (LI)
Alan Title (LMSAL)
Mark Weber (SAO)

Image above shows Hi-C launch team standing in front of the Hi-C rocket on the launcher at White Sands Missile Range.

Engineering Team:
Peter Cheimets (SAO)
Dyana Beabout (MSFC)
Brent Beabout (MSFC)
William Podgorski (SAO)
Ken McKracken (SAO)
Mark Ordway (SAO)
David Caldwell (SAO)
Henry Berger (SAO)
Richard Gates (SAO)
Simon Platt (UCLAN)
Nick Mitchell (UCLAN)

Hi-C Launch

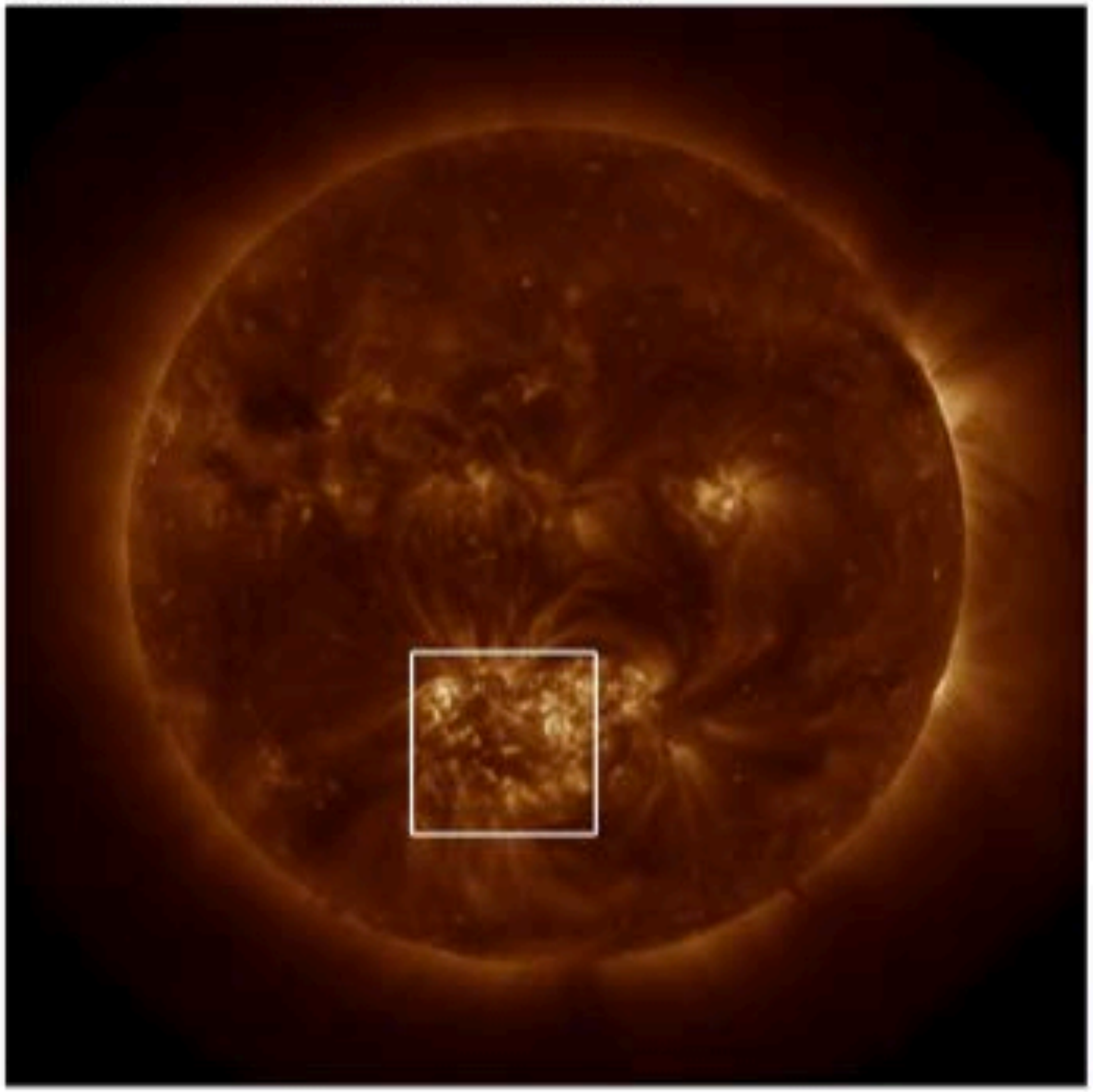
Hi-C was launched from White Sands Missile Range on 11 July 2012

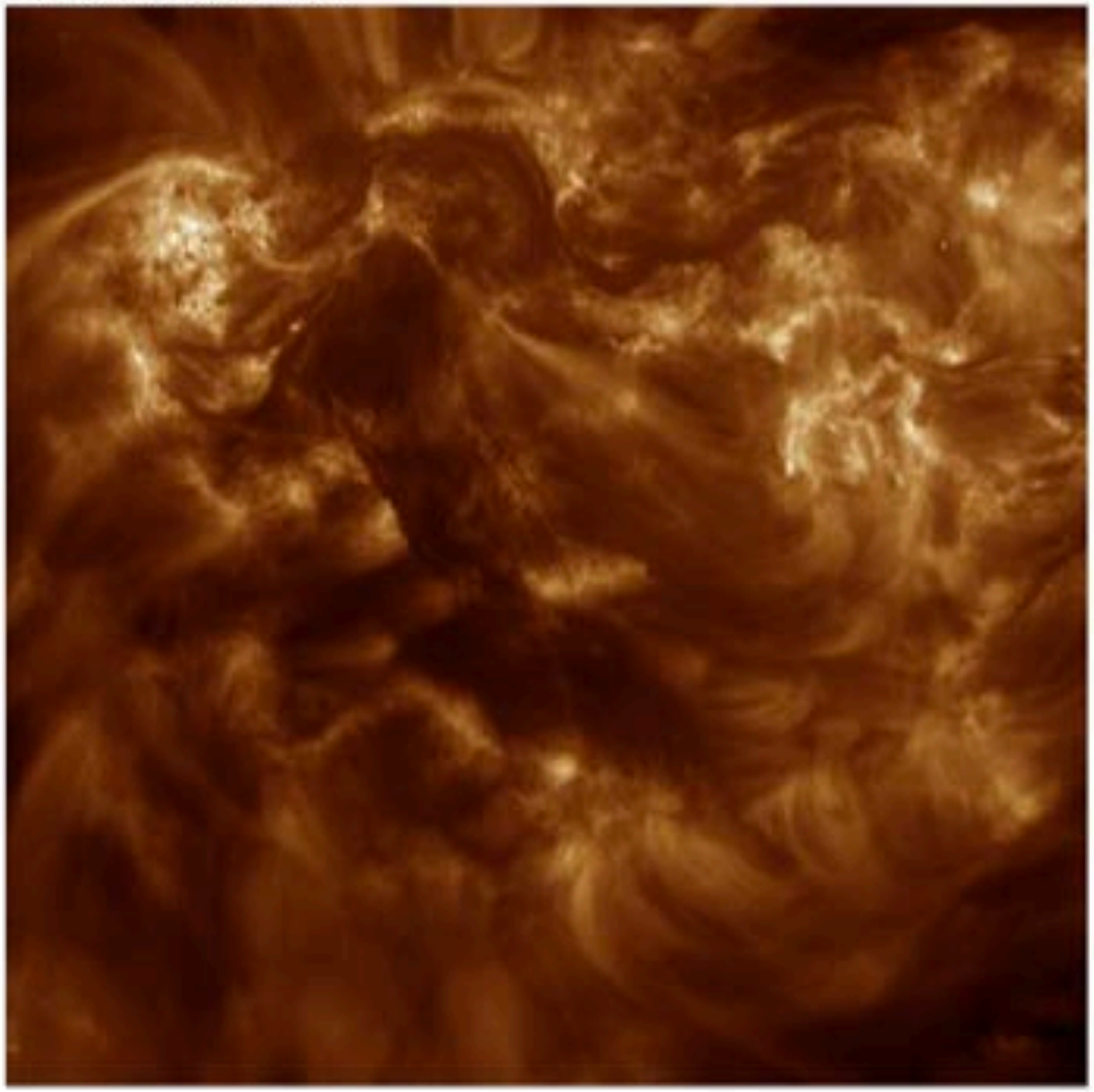
Hi-C Launch and Recovery

Hi-C recovery team

Hi-C rocket with parachute

Hi-C Target





The Hi-C target was Active Region 11520

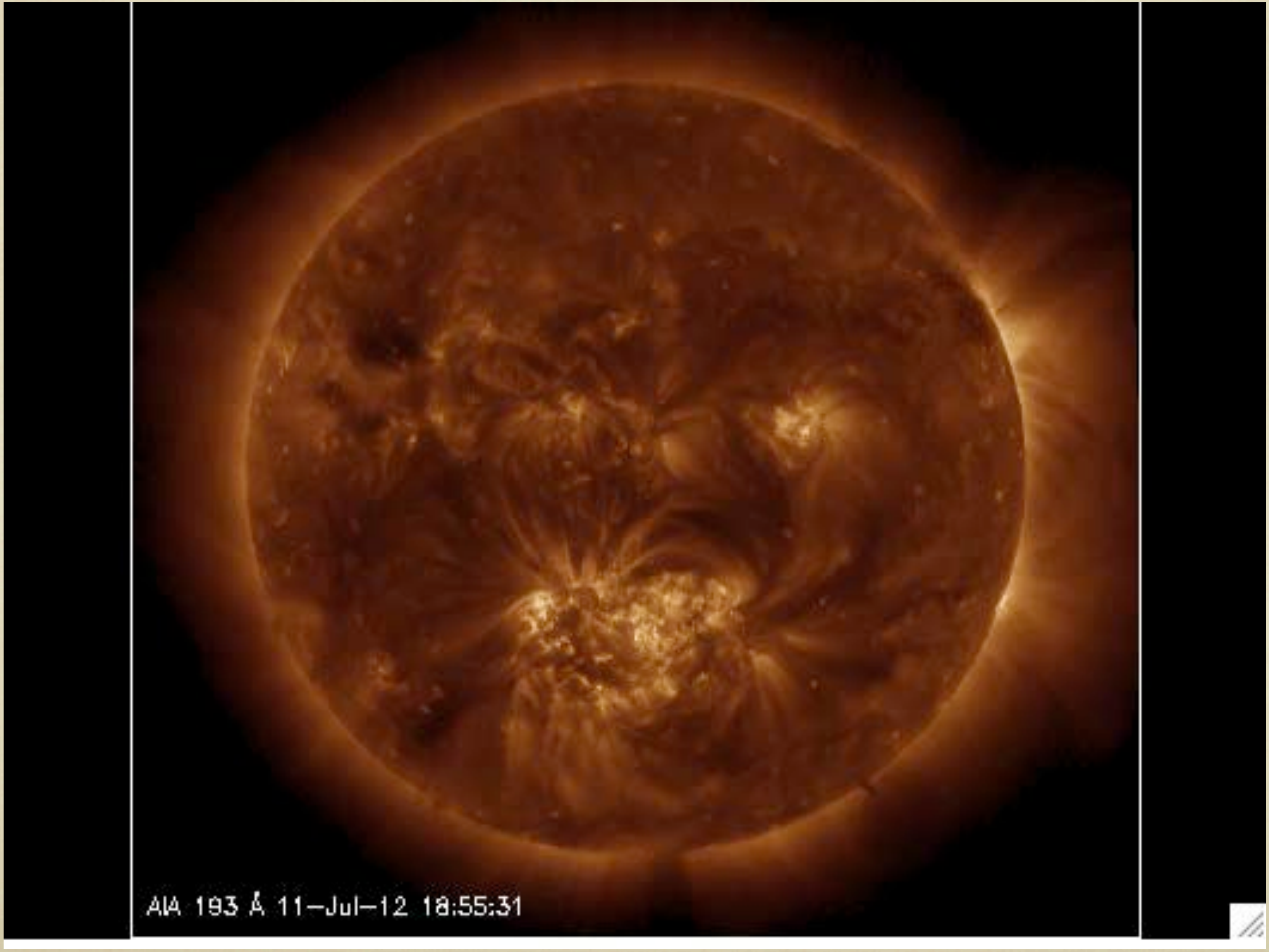
Hi-C Data

- Hi-C collected data for 345 s.
- Small shift in pointing during flight

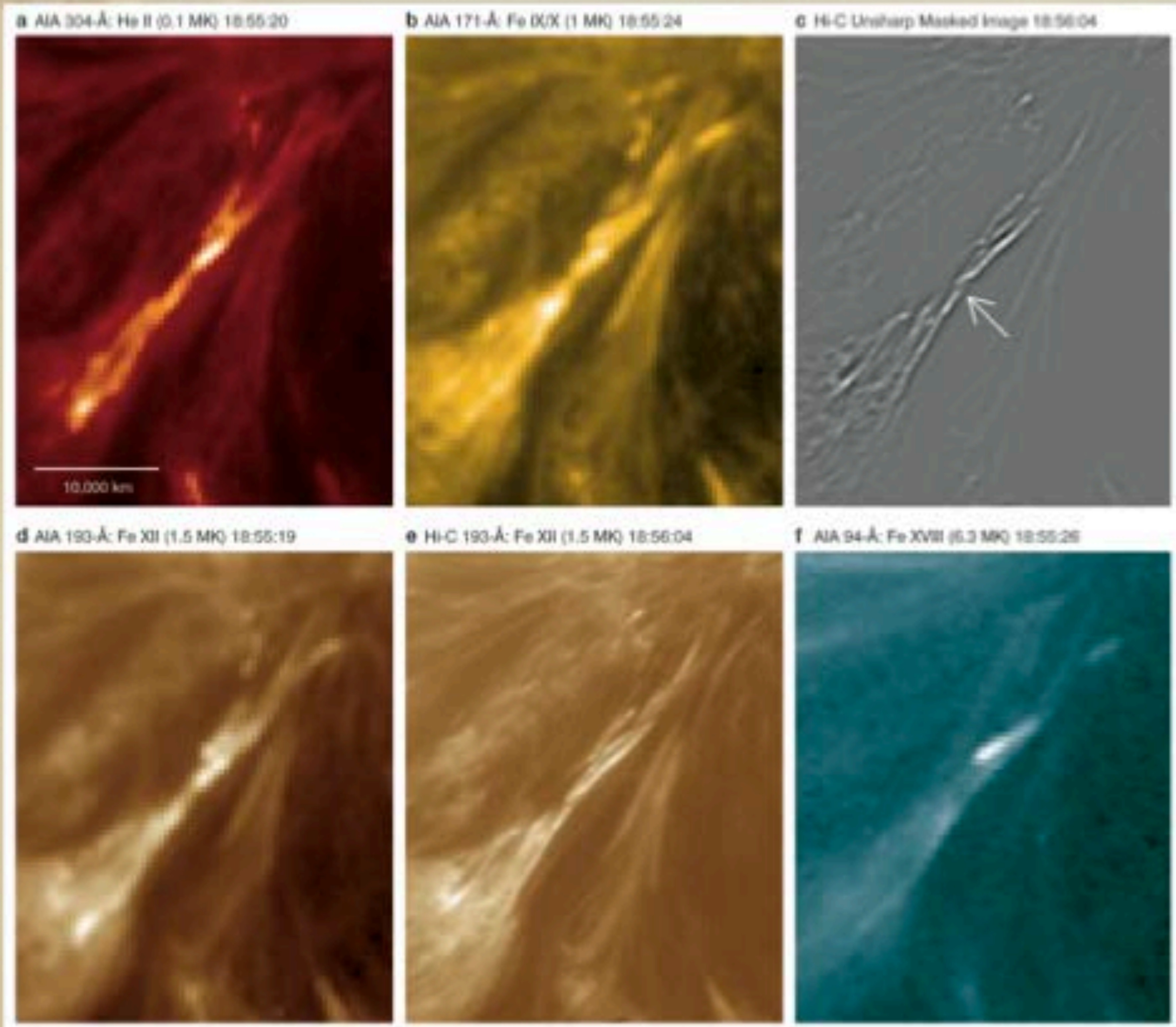
- Full frame (4kx4k) data
  - 30 full resolution images
  - 2 s exposures / 5 s cadence

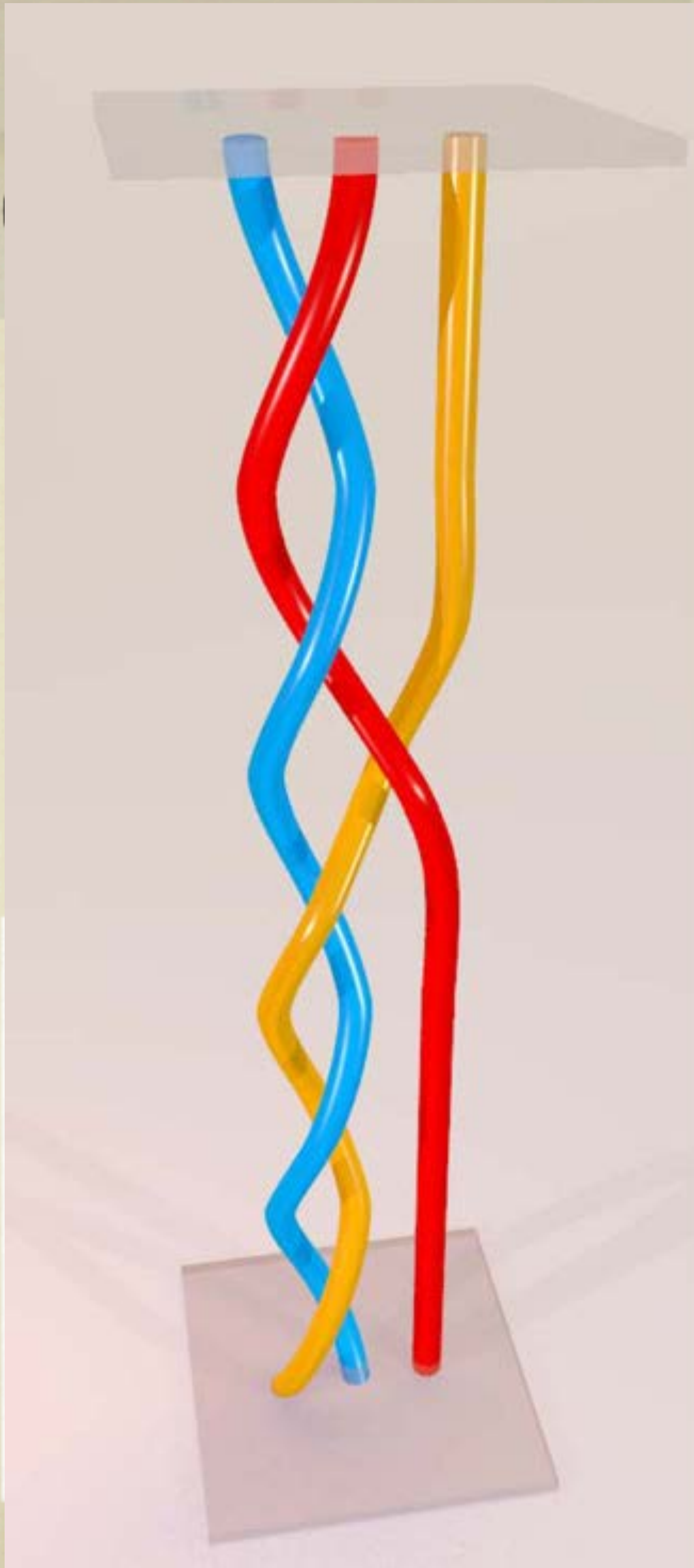
- Partial frame (1kx1k) data
  - 86 full resolution image
  - 0.5 s exposures / 1.4 s cadence

Hi-C First Results

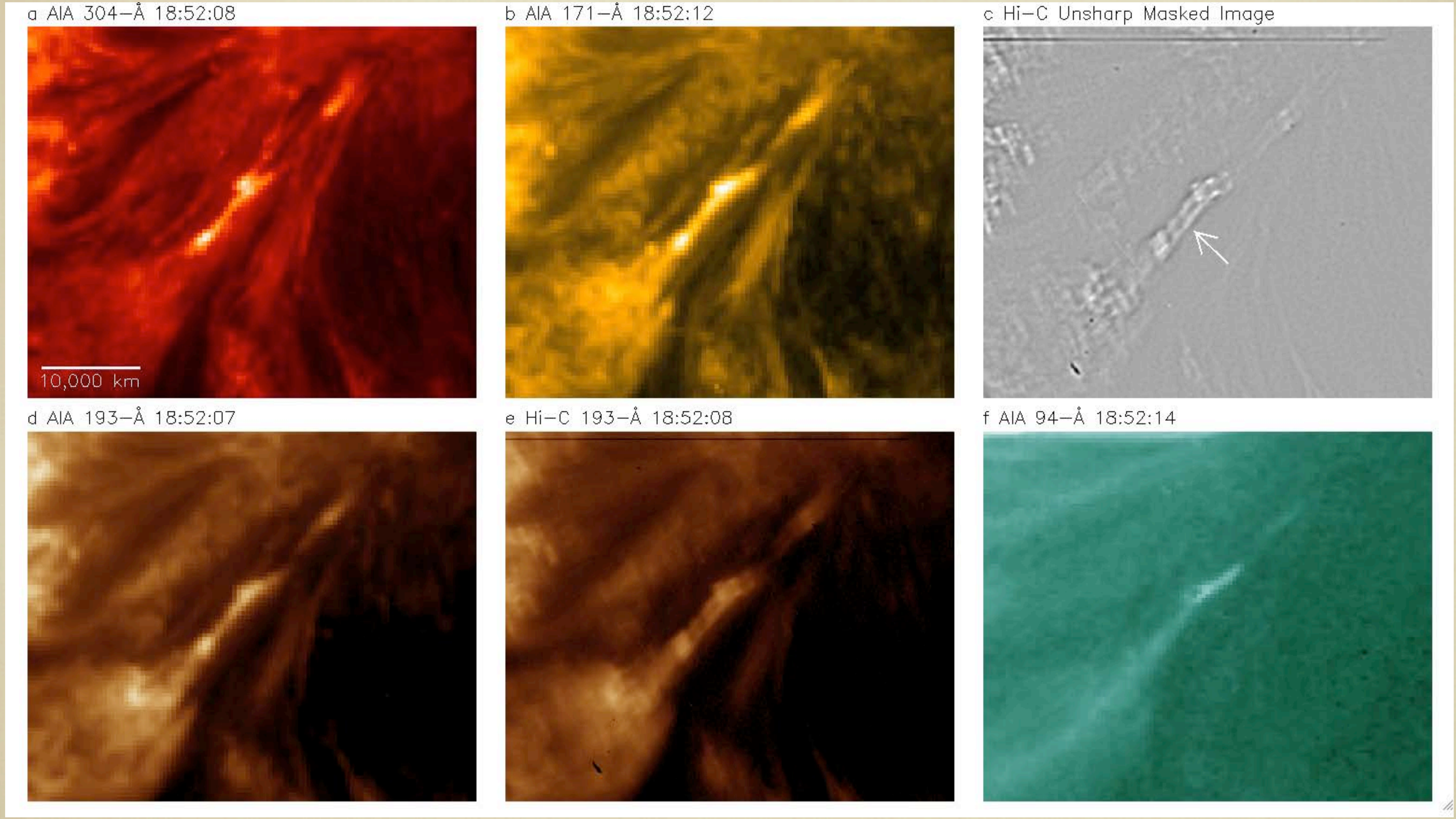


Component Reconn





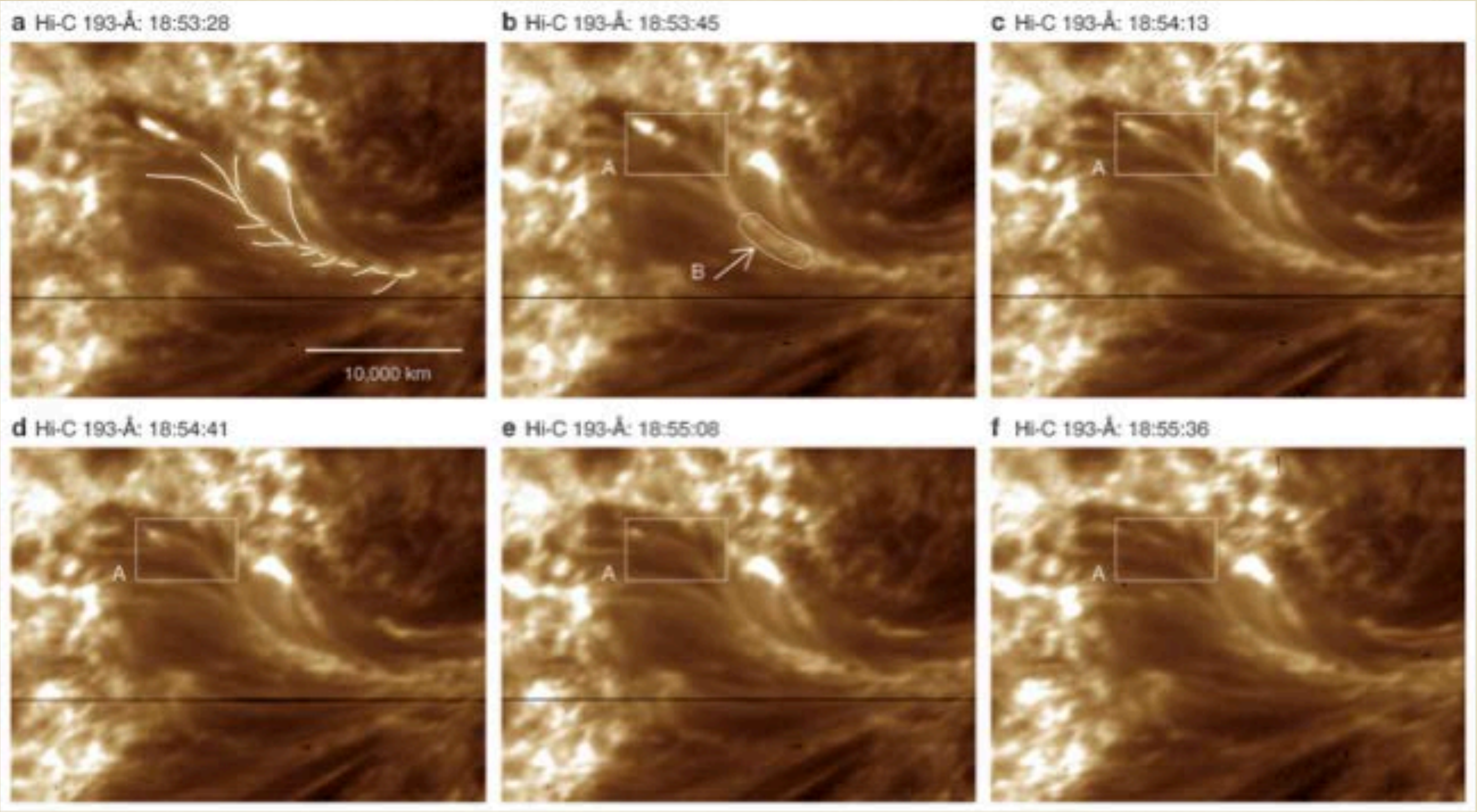
Component Reconnection



Shortly after the Hi-C flight, a small flare was observed at the field line crossing.

Cirtain et al, 2013, Nature

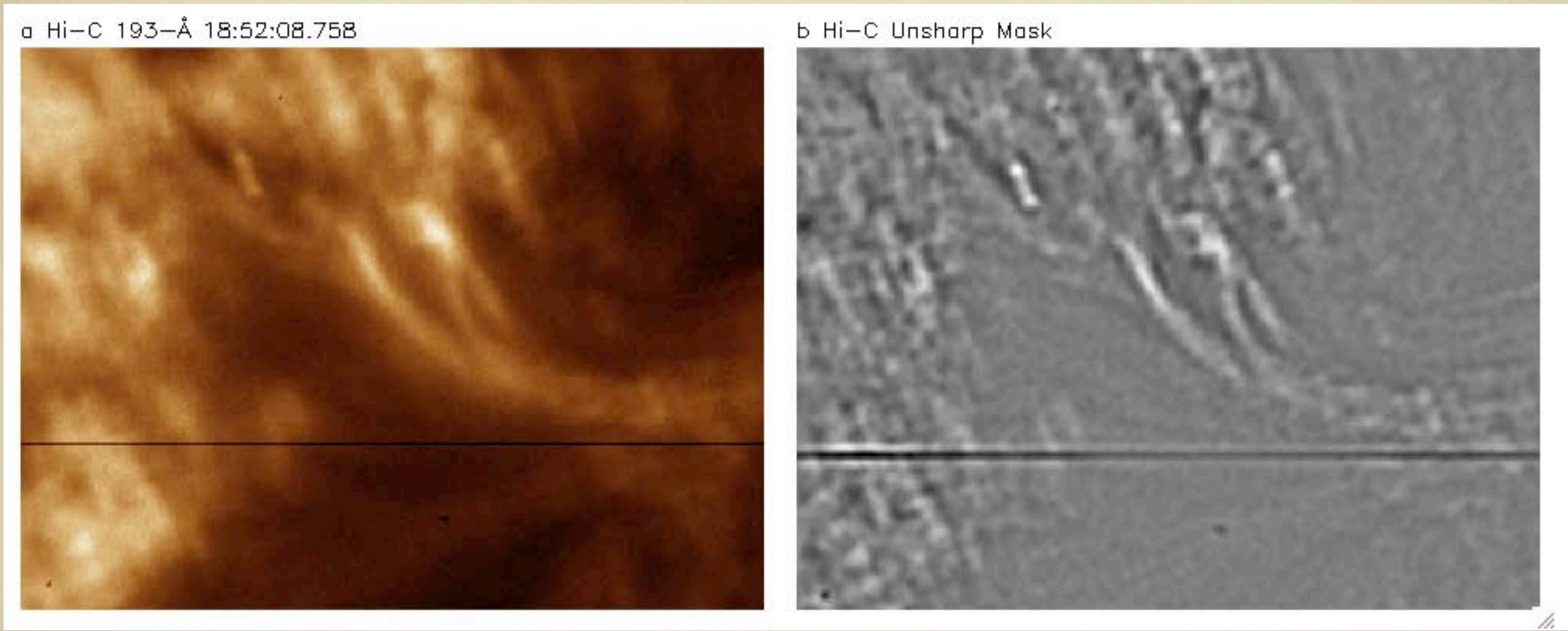
Braided Loop



Multiple strands join into this structure. It appears to unwind during Hi-C observations.

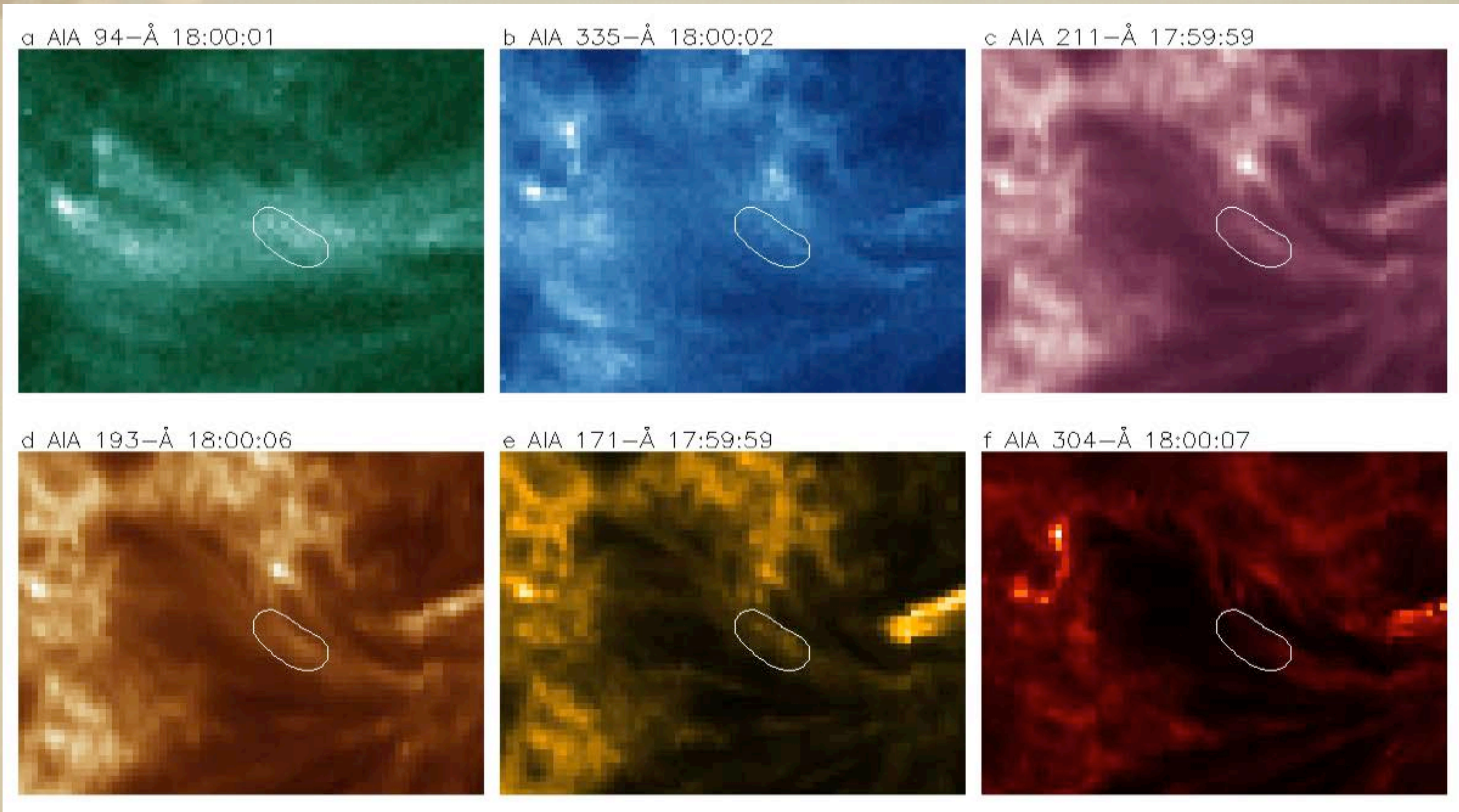
Cirtain et al, 2013, Nature

Braided Loop



Cirtain et al, 2013, Nature

Braided Loop



Loop involved in heating event prior to Hi-C flight. *Cirtain et al, 2013, Nature*

Hi-C Results

- Hi-C Sounding Rocket was the first observation of coronal braiding leading to coronal heating.
- More than 18 papers have been written on the Hi-C data, with more work currently being done.
- Hi-C will be flown again next summer (2016).

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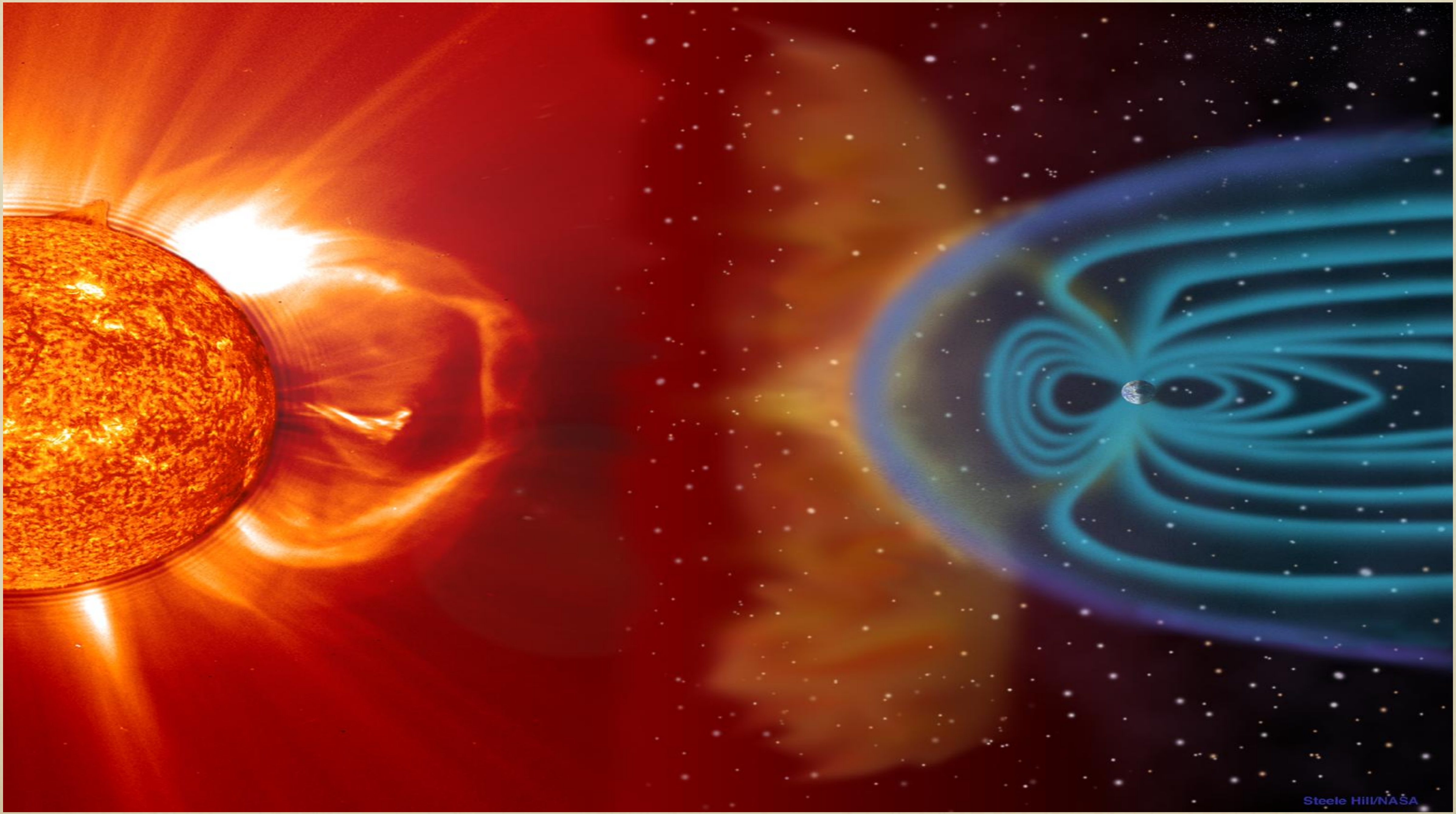
Heliophysics Research Opportunity for Undergraduates

UAHuntsville/Center for Space Plasma and Aeronomic Research (CSPAR)
& NASA/Marshall Space Flight Center



Heliophysics Research Opportunity for Undergraduates

10 Week program in Huntsville, Alabama.

May 31 – August 5, 2016

$5000 Stipend. Travel allowance, housing, meal card transportation & support to American Geophysical Union Annual Fall Meeting are provided.

Applicant must be a US citizen or permanent resident, and a full-time undergraduate student with 2.5 GPA or better.

Rising sophomores, women, and minorities are encouraged to apply.

Heliophysics Research Opportunity for Undergraduates

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

NASA

Deadline March 11, 2016

Apply at www.uah.edu/cspar/research/reu

For other research opportunities:

https://www.nsf.gov/crssprgm/reu/reu_search.jsp

Note most applications are due Mid-January – Late February, start thinking about summer 2017 now!